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LABORATORY EVALUATION OF MIL-T-83133 JP-8 FUEL IN ARMY DIESEL ENGINES

INTERIM REPORT
BFLRF No. 232

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To support the need to upgrade aviation turbine fuel JP-8 from "emergency" to "alternate" status for diesel-powered equipment and to further advance its use as a single-fuel concept, four Army diesel engines were evaluated by dynamometer tests in cyclic endurance test procedures using JP-8 fuel and compared to baseline performance using diesel fuel (DF-2).

Results showed the advantages for JP-8 fuel to include:

- Increased engine efficiency at the maximum power conditions
- Lower rate of cylinder combustion chamber deposit formation
- Less contamination of the engine lubricant
- Less wear of the upper ring area
- Lower rate of depletion of the lubricant additives

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Aviation Fuels
Jet Engine Fuels
Fuel Injectors
Automotive Fuels
Compression Ignition Engines
Multifuel Engines
Combustion
Deposits
Wear
Lubricating Oils

Block 19 - Continued

- Less corrosive wear of the engine bearings, and
- Fewer deposits on the fuel injectors.

Problems discovered by the engine dynamometer tests were:

- Reduced maximum power
- Predicted reduction in the range of vehicles operating on JP-8, which is proportionate to the reduced heating value of JP-8 compared to DF-2

JP-8 was found to be satisfactory for use in all engines tested. However, there is concern for the new GM 6.2L engine that currently powers the Commercial Utility Cargo Vehicle (CUCV) and High Mobility Multi-Purpose Wheeled Vehicle (HMMWV). Abnormal wear occurred in the fuel injection pump of the GM 6.2L engine while operating on JP-8 during an engine dynamometer test. This wear resulted in higher fuel delivery rates and erratic injection timing. Later field tests did not show such wear problems.

In general, the maximum engine power among the engines tested was reduced by the use of JP-8. Increased leakage past fuel injection pump plungers due to the lower viscosity of JP-8 resulted in reduced fueling rates. This power-reducing effect was compensated to some degree by improved thermal efficiency in all but the GM 6.2L engine.

Thus, the use of JP-8 in the diesel-engine powered vehicles holds some advantages, notably for the engine and oil durability for most engines tested. The disadvantages include reduced vehicle range and reduced maximum power. Caution is required since these tests were conducted at moderate ambient fuel temperature.

EXECUTIVE SUMMARY

Problems and Objectives: Following the conversion of JP-4 to JP-8 for use in U.S. and NATO aircraft, the U.S. Department of Defense (DOD) has adopted the single fuel for the battlefield concept, i.e., the use of one fuel for combat in ground vehicles and equipment as well as in aircraft. However, there is significant concern within the U.S. Army/DOD and the NATO community in considering the use of JP-8/F-34 as an alternate to diesel fuel DF-2 NATO Code F-54. Once approved, combat and tactical ground vehicles would be in a position to use the same fuel as aircraft, enabling the "one fuel forward" concept to be realized.

Importance of Project: The completion of this project will evaluate the effects of using JP-8 fuel in several different high-density fielded diesel engines. If the JP-8 fuel can be successfully used in these engines, which are representative of a large portion of the Army's fleet, then JP-8 fuel can be used as an alternate fuel to DF-2 in the remainder of the U.S. military compression-ignition (CI) engine fleet.

Technical Approach: In the work reported here, laboratory engine-dynamometer tests were performed using JP-8 fuel in five different high-density fielded Army diesel engines. The engines selected for the JP-8 fuel evaluations were the naturally aspirated Detroit Diesel 6V-53N, the two-stroke Detroit Diesel 6V-53T, the Teledyne Continental Motors LDT-465-1C, General Motors 6.2L, and the Cummins NHC-250. The last four engines were each operated over either the Army/Coordinating Research Council (CRC) 240-hour cycle for tracked vehicles or the Army/CRC 210-hour cycle for wheeled vehicles, depending on the type of vehicle in which a particular engine is used. Special fuel consumption tests were conducted at partial load using the first engine, the naturally aspirated 6V-53N. All engines were operated with both DF-2 and JP-8 fuel, and the differences in engine performance and durability were compared. All these tests were conducted at moderate ambient fuel temperatures.

Accomplishments: As a result of this program, JP-8 was found to be satisfactory for use in all engines tested. There were both advantages and disadvantages to the use of this fuel in the Army's CI fleet. In general, the maximum engine power among the engines tested was reduced by the use of JP-8. Increased leakage past fuel injection pump plungers due to the lower viscosity of JP-8 resulted in reduced fueling rates. The power-reducing effect was compensated to some degree by improved thermal efficiency in all but the GM 6.2L engine. Based on measurements made in the 6V-53N engine, a predicted reduction in the range of vehicles operating on JP-8 would be expected, which is proportionate to the reduced heating value of JP-8 compared to DF-2. The use of JP-8 in the diesel-engine powered vehicles holds some advantages, notably for the engine and oil durability for most engines tested. The disadvantages include expected reduction in vehicle range and reduced maximum power.

Military Impact: The results of this test program provided data to show that aircraft kerosene-type fuels can be used in diesel-powered equipment with assurance that no catastrophic fuel-related failures will occur, although an increase in fuel consumption may be observed. A major benefit to the military will be the elimination of the need to provide more than one fuel for combat, resulting in a decrease in the DOD fuel logistics burden.

FOREWORD/ACKNOWLEDGMENTS

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Deborah A. Toles; Walter E. Butler, Jr.; and **Ruben A. Alvarez** - engine data compilation, reduction, computation, and analysis.

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I. INTRODUCTION

The NATO-wide conversion from MIL-T-5624, JP-4/NATO F-40 for aircraft and VV-F-800 DF-2/NATO F-54 for ground equipment to a single fuel for all combat and tactical equipment was officially sanctioned by the United States military through DOD directive 4140.43 dated April 1988. Prior to that issue date, much test work had been done to determine the impacts of this single fuel, MIL-T-83133 JP-8/NATO F-34, on Army combat and tactical ground equipment.

This report compiles previously unreported diesel engine test data obtained using JP-8/F-34 as a fuel. While these results have not been previously reported in this form, problems identified here have, in many cases, been investigated further. These later investigations are referenced within this text.

II. BACKGROUND

The potential conversion from aviation turbine fuel Grade JP-4/MIL-T-5624/NATO Code F-40 to aviation turbine fuel Grade JP-8/MIL-T-83133/NATO Code F-34 for all aircraft operating within NATO has resulted in a program directed towards the qualification of JP-8 aviation turbine fuel for compression-ignition (diesel) engine applications. This program was preceded by a need in the early 1970's to investigate the possibility of using aviation kerosine MIL-T-5624 JP-5/NATO Code F-44 in ground equipment powered by diesel engines. The investigation consisted of surveys of the equipment manufacturers and short-term engine dynamometer testing conducted by the Army.(1,2)* Thus, as a result of the knowledge and judgment of personnel familiar with the Army's fuel requirements and equipment and limited actual testing, JP-5 was approved as an alternative to diesel fuel as described by Federal Specification VV-F-800. The approval was reflected in Army Regulation AR 703-1 Coal and Petroleum Supply and Management Activities, dated 6 September 1978, wherein JP-5 was established as an "alternate fuel" to the "primary fuel" for all diesel fuel consuming equipment.

The U.S. Army is currently investigating the acceptability of using JP-8/F-34 aviation turbine fuel in compression-ignition engines powering ground equipment/vehicles follow-

* Underscored numbers in parentheses refer to the list of references at the end of this report.

ing the same acceptance procedure adopted for JP-5. The work is being conducted under a program initiated in FY80 entitled "Development of Accelerated Fuels Qualification Procedures (AFQP)." The objective of this program was to develop more efficient and rapid military fuel qualification procedures. A basic concern in the AFQP program is to address those fuels expected to be used in the near to distant future in currently fielded military engines. Examples might include broad specification fuels, synthetic fuels, high-sulfur fuels, or the use of aviation turbine fuels in diesel-powered equipment/vehicle systems. Such is the case at hand, wherein there is significant concern within the U.S. Army/DOD and the NATO community to consider use of JP-8/F-34 as an alternate to diesel fuel DF-2/NATO Code F-54. Once approved, combat and tactical ground vehicles would be in a position to utilize the same fuel as aircraft, enabling a "one fuel forward" concept to be realized. In the work reported here, laboratory engine-dynamometer tests were performed using JP-8 fuel in five different high-density fielded Army diesel engines.

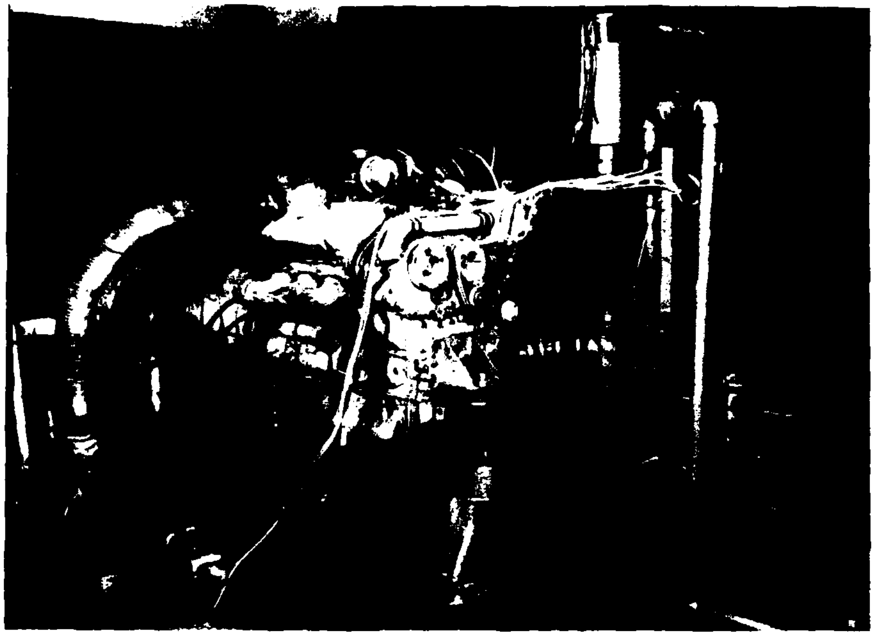
III. DETAILS OF TEST

A. Test Engines

The engines selected for the JP-8 fuel evaluations were the two-stroke General Motors (GM) Detroit Diesel (DD)* 6V-53T (Fig. 1), the naturally aspirated (GM) Detroit Diesel (DD) 6V-53N (Fig. 1), the Teledyne Continental Motors LDT-465-1C (Fig. 2), General Motors (GM) 6.2L (Fig. 3), and the Cummins NHC-250 (Fig. 4). These engines are representative of a large portion of the Army's fleet. TABLES 1 through 4 list the fielded use of the different engines.

Previous work with these engines in the Belvoir Fuels and Lubricants Research Facility (BFLRF) was concerned mainly with lubricant performance. In these earlier tests, the 6V-53T engine was found to be intolerant of low viscosity combined with high volatility in the lubricating oil, and severely scored cylinders and burned rings resulted when the volatility was below a critical limit.(3-5) The engine's sensitivity to lubricant formulation and fuel sulfur level makes it a good choice for laboratory tests since problems can be

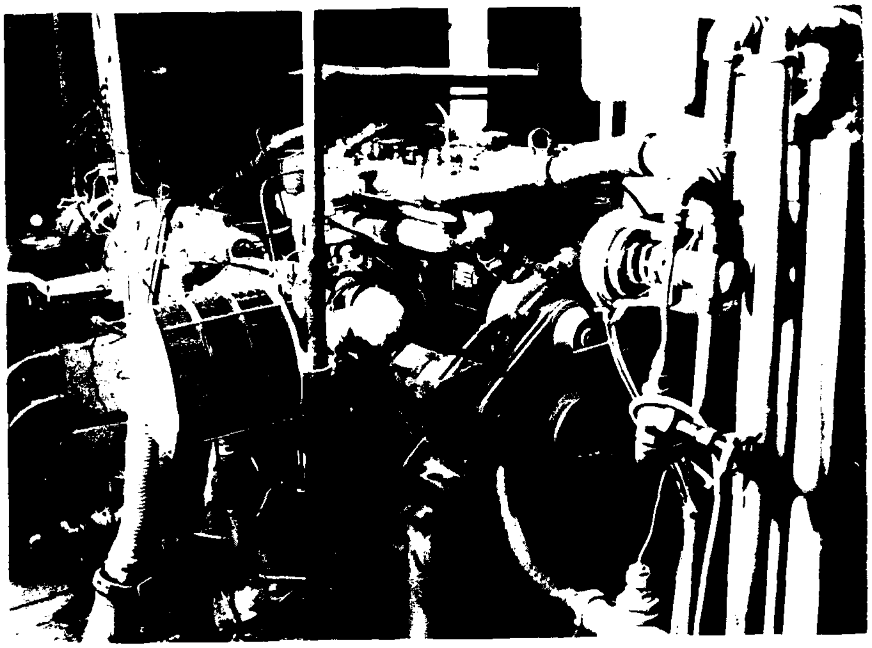
* Since this work was completed, the General Motors Detroit Diesel name has been redesignated Detroit Diesel Corporation (DDC).



DD 6V-53T Engine Specifications

	DD 6V-53T	DD 6V-53N
Engine Type	Turbocharged, Direct Injection Uniflow Scavenged, Two-Stroke Compression Ignition	Naturally Aspirated, Direct Injection, Uniflow Scavenged, Two-Stroke Compression Ignition
No. of Cylinders, arrangement	6, V	6, V
Displacement, liters (in.^{3})	5.2 (318)	5.2 (318)
Bore x Stroke, mm (in.)	98.43 x 114.30 (3.875 x 4.500)	98.43 x 114.30 (3.875 x 4.500)
Rated Power, kW (Bhp)	224 (300) at 2800 rpm	157 (210) at 2800 rpm
Rated Torque, Nm (ft-lb)	834 (615) at 2200 rpm	603 (445) at 1500 rpm
Compression Ratio	18.7:1	21:1
Oil Capacity, liters (gal.)	19 (5)	19 (5)
Engine Structure	Cast Iron Head, Block, and Liners	Cast Iron Head, Block, and Liners
Piston Material, design	Cast Iron, Trunk Type	Cast Iron, Trunk Type
Injection System	DDA N70 Unit Injectors	DDA N50 Unit Injectors

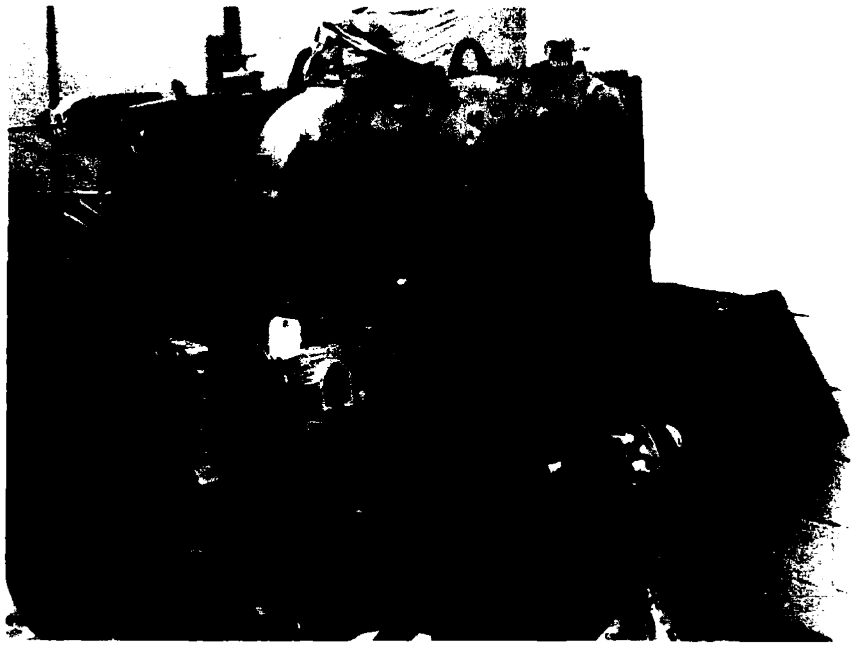
Figure 1. Specifications and installation of the Detroit Diesel 6V-53T engine



LD-465-1 and LDT-465-1C Engine Specifications

Engine Type	Turbocharged, Direct Injection Four-Stroke, Compression Ignition M.A.N. Combustion Chamber Design
Fuel	Multifuel Capacity
No. of Cylinders, arrangement	6, in-line
Displacement, liters (in.^{3})	7.8 (478)
Bore x Stroke, mm (in.)	115.8 x 123.7 (4.56 x 4.87)
Rated Power, kW (Bhp)	104 (140) at 2600 rpm, 15.5°C (60°F) and 29.82 in. Hg
Engine Structure	Cast Iron Head, Block, and Liners; Aluminum Pistons
Oil Capacity, liters (gal.)	21 (5.5)
Injection System	Bosch Rotary Distributor With Density Compensator

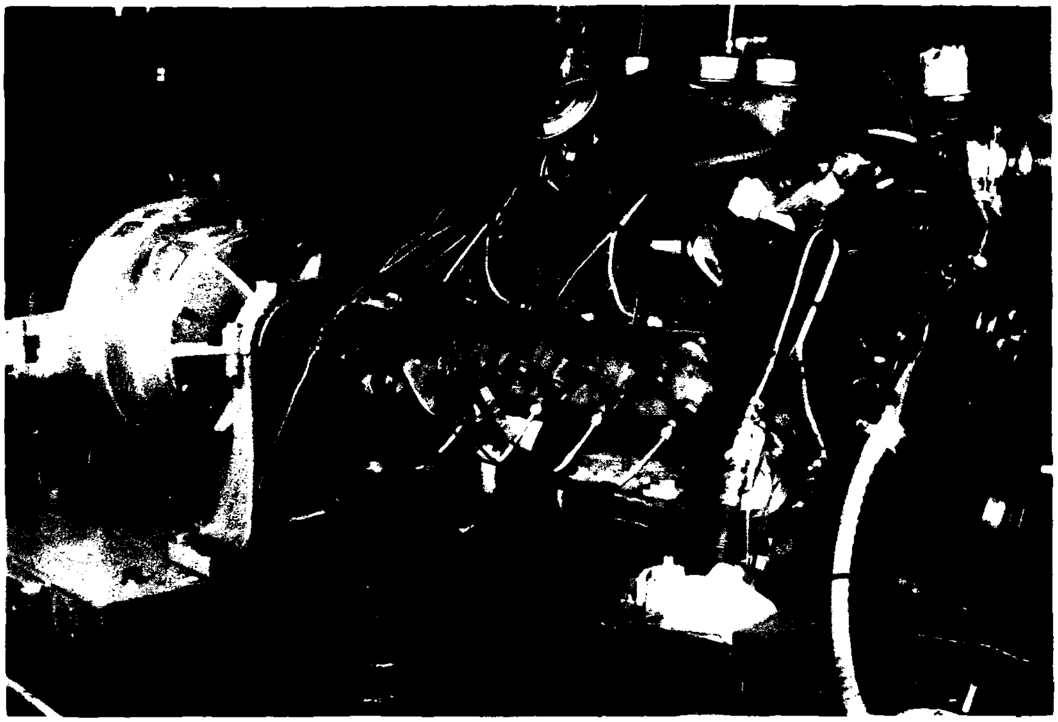
Figure 2. Specifications and installation of the Teledyne Continental Motors LDT-465-1C Engines



Cummins NHC-250 Engine Specifications

Engine Type	Direct Injected, Naturally Aspirated Four-Stroke, Compression Ignition
No. of Cylinders, arrangement	6, in-line
Displacement, liters (in.^{3})	14.0 (855)
Bore x Stroke, mm (in.)	139x (5.50 x 6.00)
Rated Power, kW (Bhp)	186 (250)
Rated Torque, Nm (ft-lb)	892 (658)
Oil Capacity, liters (gal.)	20.8 (5.5)
Engine Structure	Cast Iron Head, Block, and Liners; Aluminum Pistons
Injection System	Cummins PT System

Figure 3. Specifications and installation of the Cummins NHC-250 Engine



GM 6.2L Engine Specifications

Engine Type	Naturally Aspirated, Ricardo Swirl Pre-Combustion Chamber, Four-Stroke, Compression Ignition
No. of Cylinders, arrangement	8, V
Displacement, liters (in.^{3})	6.2 (380)
Bore x Stroke, mm (in.)	101 x 97 (3.98 x 3.82)
Rated Power, kW (Bhp)	96.6 (130) CUCV, 107.7 (145) HMMWV
Rated Torque, Nm (ft-lb)	325 (240)
Oil Capacity, liters (gal.)	6.62 (1.75)
Engine Structure	Cast Iron Head and Block (no cylinder liners) Aluminum Pistons
Injection System	Stanadyne DB-2 F/I Pump with Bosch Pintle Injectors

Figure 4. Specifications and installation of the General Motors 6.2L Engine

TABLE 1. Army Combat/Tactical Vehicles Powered by GM Detroit Diesel Two-Cycle Engines

Designation	Description	Engine Model
M106A1, A2	Mortar, Self-Propelled (SP), 107 mm	6V-53
M107	Gun, Self-Propelled, 175 mm	8V-71T
M108	Howitzer, Self-Propelled, 105 mm	8V-71T
M109A1, A2, A3	Howitzer, Medium, 155 mm	8V-71T
M110A1, A2	Howitzer, Self-Propelled, 8 inch	8V-71T
M42A1	Gun, Anti-Aircraft, SP	6V-53
M163A1	Gun, Air Defense, SP	6V-53
M113A1, A2	Carrier, Guided Missile, TOW; Personnel, Full-Tracked (FT)	6V-53
M113A1 (Stretch)	Carrier, Personnel, Stretched, FT, Armored	6V-53T
M113A2E1	Carrier, Personnel, FT, Armored	6V-53T
M125A1, A2	Mortar, Self-Propelled, FT	6V-53
M132A1	Flame Thrower, Self-Propelled	6V-53
M116	Carrier, Cargo, Amphibious	6V-53
M548	Carrier, Cargo, Tracked	6V-53
M548 (Stretch)	Carrier, Cargo, Tracked, Stretched	6V-53T
M551	Armored Reconnaissance/Airborne Assault Vehicle (Sheridan)	6V-53T
M561	Truck, Cargo, 1-1/4 T (Gamma Goat)	3-53
M792	Truck, Ambulance, 1-1/4 T	3-53
M577A1, A2	Carrier, Command Post, Light-Tracked	6V-53
M578	Recovery Vehicle, FT, SP	8V-71T
M992, XM1050	Field Artillery Ammunition Support Vehicle (FAASV), FT, SP	8V-71T
M752, M688E1	Carrier, Loader/Launcher/Transporter (Lance)	6V-53
M667	Carrier, Guided Missile, (Lance) Equipment, SP, FT	6V-53
XM727	Carrier, Guided Missile, Equipment, SP, FT	6V-53
M730, A1	Carrier, Guided Missile (Chaparral), SP, FT	6V-53
M730, A2	Carrier, Guided Missile (Chaparral), SP, FT	6V-53T
M741, A1	Chassis, Gun, AA (VULCAN), 20 mm, SP, FT	6V-53
M806E1	Recovery Vehicle, FT, Armored	6V-53
M901, A1	Improved TOW Vehicle Carrier, FT	6V-53
M981	Fire Support Team Vehicle, FT, SP	6V-53
M1015, A1	Carrier, Electronic Shelter, FT, SP	6V-53
M1059	Carrier, Smoke Generator, FT, SP	6V-53
M113A1, A2	Fitters Vehicle, FT, SP	6V-53
M878, A1	Truck, Tractor, 5 T, Yard Type	6V-53T
M911	Truck, Tractor, Heavy Equipment Transporter	8V-92TA
M746	Truck, Tractor, Heavy Equipment Transporter	12V-71T
M977, 985	Truck, Cargo, Tactical, 8 x 8 HEM	8V-92TA
M978	Truck, Tank, FT, 2500 gal.	8V-92TA
M983	Truck, Tractor, Tactical	8V-92TA
M984	Truck, Wrecker, Tactical	8V-92TA

TABLE 2. Army Vehicles Powered by Teledyne Continental Motors LD/LDS/LDT-465 Engines*

Designation	Description	Engine Model
M44A2	Chassis, Truck: 6 x 6	LD-465-1
M45A2	Chassis, Truck: 6 x 6	LD-465-1
M45A2G	Chassis, Truck: 6 x 6	LD-465-1
M46A2C	Chassis, Truck: 6 x 6	LD-465-1
M621	Chassis, Truck: 6 x 6	LD-465-1
M622	Chassis, Truck: 6 x 6	LD-465-1
M623	Chassis, Truck: 6 x 6	LD-465-1
M624	Chassis, Truck: 6 x 6	LD-465-1
M40A2	Chassis, Truck: 6 x 6	LDS-465-1A
M40A2C	Chassis, Truck: 6 x 6	LD-465-1A
M63A2	Chassis, Truck: 6 x 6	LDS-465-1A
M63A2C	Chassis, Truck: 6 x 6	LDS-465-1A
M35A2	Truck, Cargo: 6 x 6	LD-465-1
M35A2C	Truck, Cargo: 6 x 6	LD-465-1
M36A2	Truck, Cargo: 6 x 6	LD-465-1
M621	Truck, Cargo: 6 x 6	LD-465-1
M54A2C	Truck, Cargo: 6 x 6	LD-465-1A
M55A2	Truck, Cargo: 6 x 6	LD-465-1A
M656	Truck, Cargo: 8 x 8	LD-465- (TC)
M342A2	Truck, Dump: 6 x 6	LD-465-1
M624	Truck, Dump: 6 x 6	LD-465-1
M51A2	Truck, Dump: 6 x 6	LD-465-1A
M49A2C	Truck, Tank: Fuel, 6 x 6, 4542 L (1200 gal.)	LD-465-1
M50A2	Truck, Tank: Water, 6 x 6, 3785 L (1000 gal.)	LD-465-1
M622	Truck, Tank: Fuel Servicing, 6 x 6, 4542 L (1200 gal.)	LD-465-1
M275A2	Truck, Tractor: 6 x 6	LD-465-1
M52A2	Truck, Tractor: 6 x 6	LD-465-1A
M246A2	Truck, Tractor: Wrecker, 6 x 6	LDS-465
M109A3	Truck, Van: Shop, 6 x 6	LD-465-1
M185A2	Truck, Van: Shop, 6 x 6	LDS-427-2
M185A3	Truck, Van: Shop Repair, 6 x 6	LD-465-1
M623	Truck, Van: Shop, 6 x 6	LD-465-1
M291A2	Truck, Van: Expansible, 6 x 6	LDS-465-1A
M291A2C	Truck, Van: Expansible, 6 x 6	LDS-465-1A
M543A2	Truck, Wrecker: Medium, 6 x 6	LDS-465-1A

* Source: TM 43-0001-31, Equipment Data Sheets for TARCOM Equipment, July 1978.
Note: The LDT-465-1C engine is used interchangeably in vehicles utilizing the LD-465-1 engine.

TABLE 3. Army Vehicles Powered by the Cummins NHC-250 Engine

Designation	Description	Engine Model
M815	Truck, Bolster: 5 Ton	NHC-250
M924	Truck, Cargo: 5 Ton	NHC-250
M813	Truck, Cargo: 5 Ton	NHC-250
M926	Truck, Cargo: 5 Ton	NHC-250
M813	Truck, Cargo: 5 Ton	NHC-250
M814	Truck, Cargo: 5 Ton	NHC-250
M927	Truck, Cargo: 5 Ton	NHC-250
M928	Truck, Cargo: 5 Ton	NHC-250
M814	Truck, Cargo: 5 Ton	NHC-250
M813A1	Truck, Cargo Dropside: 5 Ton	NHC-250
M923	Truck, Cargo Dropside: 5 Ton	NHC-250
M813A1	Truck, Cargo Dropside: 5 Ton	NHC-250
M925	Truck, Cargo Dropside: 5 Ton	NHC-250
M817	Truck, Dump: 5 Ton	NHC-250
M929	Truck, Dump: 5 Ton	NHC-250
M817	Truck, Dump: 5 Ton	NHC-250
M930	Truck, Dump: 5 Ton	NHC-250
M821	Truck, Stake Bridge Trans: 5 Ton	NHC-250
M819	Truck, Trac/Wrecker: 5 Ton	NHC-250
M818	Truck, Tractor: 5 Ton	NHC-250
M931	Truck, Tractor: 5 Ton	NHC-250
M932	Truck, Tractor: 5 Ton	NHC-250
M818	Truck, Tractor: 5 Ton	NHC-250
M820	Truck, Van Expansible: 5 Ton	NHC-250
M820A2	Truck, Van Expansible: 5 Ton	NHC-250
M934	Truck, Van Expansible: 5 Ton	NHC-250
W/LFTM935	Truck, Van Expansible: 5 Ton	NHC-250
M936	Truck, Wrecker: 5 Ton	NHC-250
M816	Truck, Wrecker: 5 Ton	NHC-250

expected to develop quickly, minimizing test time.(6,7) The naturally aspirated version of this engine was used for developing partial-load fuel consumption data. This short-term testing provided a better estimate of fuel consumption changes with JP-8 than the full-power endurance testing.

The LDT-465 engine produces a high blow-by flow rate that stresses the lubricant's additive package. Experience shows this engine also tends to thermally stress the oil leading to viscosity increases.(8-11) The resultant thickened oil can cause pumpability problems at cold start, thus creating excessive wear.

TABLE 4. Army Vehicles Powered by the General Motors 6.2L Diesel Engine

Designation	Description	Engine Model
M996	Truck, Ambulance: 2 Liter, HMMWV	GM 6.2L LL4
M997	Truck, Ambulance: 4 Liter, HMMWV	GM 6.2L LL4
M1010	Truck, Ambulance: TAC, 5/4 Ton	GM 6.2L LL4
M1008	Truck, Cargo: Tactical, 5/4 Ton	GM 6.2L LL4
M1008A1	Truck, Cargo: Tactical, 5/4 Ton	GM 6.2L LL4
M1028	Truck, Cargo: Tactical, 5/4 Ton	GM 6.2L LL4
M1025	Truck, Utility: 4 x 4, 11/4 Ton	GM 6.2L LL4
M1026	Truck, Utility: 4 x 4, 11/4 Ton	GM 6.2L LL4
M1038	Truck, Utility: C60, 11/4 Ton	GM 6.2L LL4
M998	Truck, Utility: C60, 11/4 Ton	GM 6.2L LL4
M1037	Truck, Utility: S250, HMMWV	GM 6.2L LL4
M1009	Truck, Utility: Tactical, 3/4 Ton	GM 6.2L LL4
M966	Truck, Utility: Tow Carrier, HMMWV	GM 6.2L LL4

Army experience shows the Cummins NHC-250 engine to be rather insensitive in that it does not generate unusual stress on the lubricant.(12) The "PT" or pressure-time fuel injection system is unique in design and is tolerant of off-specification fuels.The GM 6.2L engine is a relatively new engine to the Army. Although it is currently being used in only two Army vehicles, the High Mobility Multi-purpose Wheeled Vehicle (HMMWV) and the Commercial Utility Cargo Vehicle (CUCV), the Army will field over 200,000 of these units. The engine testing performed during this program represents the initial experience with this engine for the BFLRF. It was chosen for the program due to the large numbers that will be fielded, rather than any known fuel or lubricant sensitivities.

Various combustion systems were represented by the engines. This was necessary in order to identify combustion-related problems that could arise due to a particular fuel/engine combination. Such effects may not have been a problem in the past since the physical properties of the petroleum-based fuels did not differ significantly. However, today, with the possibility of using a wide variation of fuels, for example, variable quality/broad specification fuels and/or emergency fuels, all aspects of the combustion

process, from the atomization of the fuel through evaporation and the chemical reactions can be quite different.

B. Test Cycles

The different engines were each operated over either the Army/Coordinating Research Council (CRC) 240-hour cycle for tracked-vehicles, or the Army/CRC 210-hour cycle for wheeled-vehicles, depending on the type of vehicle in which a particular engine is used.

A description of the 240-hour tracked-vehicle cycle is given in TABLE 5. This cycle, used for the 6V-53T tests, has been correlated to 6437 kilometers (4000 miles) of proving ground operation.(13) The 6V-53T was the only engine to use this test cycle.

TABLE 5. Army/CRC 240-Hour Tracked-Vehicle Endurance Cycle

Period*	Time, hr	Rack/Throttle Setting	Coolant Jacket-Out Temp, °C (°F)
1	0.5	Idle	38 (100)
	2.0	Maximum Power	77 (170)
	0.5	Idle	38 (100)
	2.0	Maximum Torque	77 (170)
2	0.5	Idle	38 (100)
	2.0	Maximum Power	77 (170)
	0.5	Idle	38 (100)
	2.0	Maximum Torque	77 (170)
3	0.5	Idle	38 (100)
	2.0	Maximum Power	77 (170)
	0.5	Idle	38 (100)
	2.0	Maximum Torque	77 (170)
4	0.5	Idle	38 (100)
	2.0	Maximum Power	77 (170)
	0.5	Idle	38 (100)
	2.0	Maximum Torque	77 (170)
5	4	5 min idle, followed by shutdown	--

* These five periods yield 20 hours of running with a 4-hour shutdown; this cycle is repeated 12 times for a total test time of 240 hours.

The other engines were operated over the 210-hour wheeled-vehicle cycle described in TABLE 6. This cycle has been correlated to 32,185 kilometers (20,000 miles) of proving ground experience.(13) The NATO AEP-5 400-hour diesel engine test procedure was used for a single evaluation in the GM 6.2L engine.

TABLE 6. Army/CRC 210-Hour Wheeled-Vehicle Endurance Cycle

Period*	Time, hr	Rack/Throttle Setting	Coolant Jacket-Out Temp, °C (°F)
1	2	5 min idle followed by slow acceleration to maximum power	82 (180)
2	1	Idle	38 (100)
3	2	Maximum Power	82 (180)
4	1	Idle	38 (100)
5	2	Maximum Power	82 (180)
6	1	Idle	38 (100)
7	2	Maximum Power	82 (180)
8	1	Idle	38 (100)
9	2	Maximum Power	82 (180)
10	10	5 min idle followed by shutdown	--

* These ten periods yield 14 hours of running with a 10-hour shutdown; this cycle is repeated 15 times for a total test time of 210 hours.

C. Test Fuels

The base fuel was reference No. 2 diesel fuel supplied by Howell Hydrocarbons, Inc. of San Antonio, TX. The specification requirements for this fuel, commonly referred to as "Cat fuel," are set forth in section 5.2, methods 354 and 355 of Federal Test Method Standard (FTMS) 791C and described in Appendix F of ASTM STP 509A, Part I and II.(14)

This test fuel is a straight-run, mid-range natural sulfur fuel manufactured under closely controlled refinery operation to minimize batch-to-batch compositional and physical property deviations. Properties of the test fuel are given in TABLE 7 and compared with requirements of Cat fuel and VV-F-800.(15)

TABLE 7. Analysis of Reference No. 2 DF (Cat Fuel), Batch 85-2 (AL-14069-F)

Test	ASTM Method	Test Fuel AL-14069-F	Requirements	
			Cat Fuel (1)	VV-F-800D (2)
Gravity °API	D 287	34.5	32-35	(a)
Specific Gravity, 15.6/15.6°C	D 1298	0.8524	(a)	0.815-0.860
Viscosity, cSt at 100°F (37.8°C)	D 445	3.12	3.0-4.0	(a)
at 104°F (40°C)	D 445	2.98	(a)	1.9-4.1
Distillation, °F (°C)	D 86			
Initial Boiling Point		402 (206)	Report	(a)
10% Recovered		462 (239)	Report	(a)
50% Recovered		517 (269)	500-530 (260-277)	Report
90% Recovered		611 (322)	580-620 (304-327)	675 (357) max
End Point		663 (351)	650-690 (343-366)	698 (370) max
% Recovered		99		(a)
% Residue		1		(a)
Flash Point, °F (°C)	D 93	180 (82)	100 (37.8) min	133 (56) min
Pour Point, °F (°C)	D 97	9 (-13)	20 (-7) max	0 (-18) max
Cloud Point, °F (°C)	D 2500	14 (-10)	Report	9 (-13) max
Copper Corrosion, 3 hr at 210°F, Rating	D 130	1A	No. 2 max	1
Carbon Residue on 10% Bottoms, Ramsbottom wt%	D 524	0.11	0.20 max	0.20 max
Water and Sediment, vol%	D 1796	0.01	0.05 max	0.10 max
Neutralization Number, mg KOH/g	D 974	0.02	(a)	0.10
Total Acid No., mg KOH/g	D 664	(a)	0.15 max	(a)
Ash, wt%	D 482	0.01	0.01 max	0.02 max
Net Heat of Combustion, Btu/lb	D 240	18,279	(a)	(a)
MJ/kg		42,516	(a)	(a)
Cetane Number	D 613	52	45-51	45 min
Cetane Index	D 976	47	(a)	(a)
Carbon, wt%	D 3178	86.24	(a)	(a)
Hydrogen, wt%	D 3178	12.19	(a)	(a)
Sulfur, wt%	D 2622	0.41	0.370-0.430	0.30 max
Cracked Stocks			None	

(a) No requirement.
(1) ASTM STP 509A, Part I and II, Appendix F.
(2) Requirements for grade DF-2 (NATO F-54).

The special test fuel used in these endurance runs was obtained from Sun Tech and met the requirements of MIL-T-83133 Aviation Turbine Fuel, JP-8.(16) This fuel was delivered to BFLRF in bulk, at which time it was assigned a fuel designation number of AL-14216-F. The fuel properties determined at BFLRF are given in TABLE 8 and are also compared to the specification requirements for MIL-T-83133/NATO F-34. This particular fuel meets the NATO JP-8 fuel requirements critical for diesel engine performance. The cetane number, although not a specification requirement for jet fuels, was found to be 41. As shown in Table 7, the minimum cetane number requirement for VV-F-800D diesel fuel is 40. Thus, ignition/combustion-related problems would not be anticipated. A comparison of fuel properties related to diesel engine performance is provided in TABLE 9 for diesel fuel VV-F-800 grades DF-A, DF-1, and DF-2; naval distillate fuel MIL-F-16884; and JP-5 and JP-8 aviation turbine engine fuels.

D. Test Procedures

A complete description of the test procedure for each individual engine is given in the appropriate appendix. In general, prior to each test the engines were completely disassembled, critical parts were replaced with new components where necessary, and the engine was reassembled. The manufacturers rebuild specifications were followed for all parts, and measurements of the critical components were recorded.

Following the calibration of the instrumentation, the engine was run-in according to the cycle given in TABLE 10. Before-test power curves were run on both the JP-8 test fuel and the baseline Cat fuel. The oil was changed following engine run-in.

E. Test Lubricants

Two different Army reference oils were used in the engine tests. A qualified MIL-L-2104D (17) OE/HDO-30 Army reference oil, utilizing a magnesium detergent-dispersant and with a sulfated ash content of 0.84 wt%, was used in the 210-hour testing. The 6V-53T tests that were 240 hours in duration used the Coordinating Research Council (CRC) reference engine oil REO-203, an SAE 30-grade lubricant. The REO-203 oil uses a calcium detergent-dispersant and has a sulfated ash content of 0.93, similar to the MIL-L-2104D oil. A further listing of the oil properties and composition is given in TABLE 11.

TABLE 8. Properties of JP-8 Test Fuel

Property	Method	MIL-T-83133B JP-8/NATO F-34 Requirements	Test Fuel AL-14216-F
Color	D 156	(a)	+15 (Saybolt)
Total Acid Number, mg KOH/g	D 3242	0.015 max	0.005
Aromatics, vol%	D 1319	25.0 max	19.0
Olefins, vol%	D 1319	5.0 max	0
Sulfur, total wt% (XRF)	D 4294	0.3 max	<0.01
Mercaptan Sulfur, wt%	D 3227	0.001 max	0.0002
Distillation, °C	D 86		
Initial Boiling Point		(a)	171
10% Recovered		186 max	184
20% Recovered		(a)	188
50% Recovered		(a)	200
90% Recovered		(a)	222
End Point		330 max	238
Flash Point, °C	D 93	38 min	56
Gravity, °API	D 1298	37-51	40.3
Density, kg/L at 15°C	D 1298	0.775-0.840	0.8232
Freezing Point, °C	D 2386	-50 max	-55
Kinematic Viscosity at -20°C, cSt	D 445	8.0 max	4.14
Kinematic Viscosity at 40°C, cSt	D 445	NR*	1.26
Net Heat of Combustion, MJ/kg (Btu/lb)		42.8 (18,400) min	43.106 (18,532)
Hydrogen Content, wt%		13.5 min	13.69
Smoke Point, mm	D 1322	19 min	22.2
Copper Corrosion, 2 hr at 100°C	D 130	1B max	1A
Thermal Stability (JFTOT), Code	D 3241	<3	1
Change in Pressure Drop, mm Hg		25 max	0
Existent Gum, mg/100 mL	D 381	7.0 max	0.2
Particulate Matter, mg/L	D 2276	1.0 max	1.1 (b)
Water Reaction, interface rating	D 1094	1b	1b
Water Separation Index, modified	D 2550	70 max	--
Fuel System Icing Inhibitor		0.10-0.15	0.01, 0.04
Fuel Electrical Conductivity, pS/m	D 2624	200-600	170, 90
Filtration Time, minutes, Apdx A	MIL-T-5624	15 max	72
Cetane Number		(c)	41
BOCLE, scar diameter, mm		(c)	0.34

* NR = Not required.
(a) Report.
(b) Underlined values outside of specification limits.
(c) No requirement.

TABLE 9. **Comparative Fuel Properties Related to Diesel Engine Performance**

Properties	Method	VV-F-800D DF-A	VV-F-800D DF-1	VV-F-800D DF-2	MIL-F-16884H NDF	MIL-T-5624-M JP-5	MIL-T-83133B JP-8
Flash Point, °C, min	D 93	38	38	52	60	60	38
Cloud Point, °C, max	D 2500	-51	*	*	-1	NR**	NR
Pour Point, °C	D 97	Rpt	Rpt	Rpt	-6	NR	NR
Freezing Point, °C, max	D 2386	NR	NR	NR	NR	-46	-47
Kinematic Viscosity at 40°C, cSt	D 445	1.1 to 2.4	1.3 to 2.9	1.9 to 4.4	1.7 to 4.3	NR	NR
Kinematic Viscosity at -20°C, cSt, max	D 445	NR	NR	NR	NR	8.5	8.0
Distillation, °C	D 86						
10% recovered, max		NR	NR	NR	NR	205	205
20% recovered, max		NR	NR	NR	NR	Rpt	Rpt
50% recovered, max		Rpt	Rpt	Rpt	Rpt	Rpt	Rpt
90% recovered, max		288	288	338	357	Rpt	Rpt
End Point, max		300	330	370	385	300	300
Residue, vol%, max		3	3	3	3	1.5	1.5
Carbon Residue on 10% Bottoms, wt%, max	D 524	0.10	0.15	0.35	0.20	NR	NR
Sulfur, mass%, max	D 2622	0.25	0.50	0.50	1.00	0.40	0.30
Cu Corrosivity	D 130						
3 hrs at 50°C, max		3	3	3	NR	NR	NR
2 hrs at 100°C, max		NR	NR	NR	1	1	1
Ash, wt%, max	D 482	0.01	0.01	0.01	0.005	NR	NR
Accelerated Stability, mg/100 mL, max	D 2274	1.5	1.5	1.5	1.5	NR	NR
Neutralization Number, mg KOH/g, max	D 974	0.05	NR	NR	0.3	0.015	0.015
Particulate Contamination, mg/L, max	D 2276	10	10	10	NR	1.0	1.0
Cetane Number, min	D 613	40	40	40	45	NR	NR
Net Heat of Combustion, MJ/kg, min	D 2382 or D 3338	NR	NR	NR	NR	42.6	42.8

* Specified according to anticipated low ambient temperature at use location.
** NR = No requirement.

TABLE 10. Engine Run-In Cycle

Cummins NHC-250

Engine Speed, rpm	Power, Obs Bhp	Time, min.
1575	125	26
2100	188	15
2100	213	15
2100	225	15
Full Power Check	250 ± 7	15
2100	Adjusted full throttle to 97 lb/hr fuel flow rate	

LDT-465-1C

Engine Speed, rpm	Power, Obs Bhp	Time, min.
1000	15	30
1400	15	30
1800	35	30
2200	65	60
2400	100	60
2600	140	30
2600	Adjusted full rack to 66-67 lb/hr fuel flow rate	

GM 6V-53T

Engine Speed, rpm	Power, Obs Bhp	Time, min.
1000	10	10
2800	10	30
1800	30	15
2200	130	30
2500	200	30
2800	225	30

GM 6.2L

RPM	Torque, lb-ft	Time	Bhp Computed
1. 1000	87	30 min.	17
2. 1500	93	30 min.	27
3. 1800	98	30 min.	34
4. 2000	102	30 min.	39
5. 2200	106	30 min.	44
6. 2400	113	30 min.	52
7. 2500	117	30 min.	56
8. 2600	121	30 min.	60
9. 2700	125	30 min.	64
10. 2800	127	30 min.	68
11. 2900	129	30 min.	71
12. 3000	132	30 min.	75
13. 3100	134	30 min.	79
14. 3200	137	30 min.	83
15. 3300	140	30 min.	88
16. 3400	142	30 min.	92
17. 3500	145	30 min.	97
18. 3600	146	30 min.	100
19. 3700	147	30 min.	104
20. 3800	148	30 min.	107
21. 3900	149	30 min.	110
		10.5 Hrs.	

Full Load

		Time	Bhp
3000	Report	1 hr.	Max
3200	Report	1 hr.	Max
3400	Report	1 hr.	Max
3600	Report	1 hr.	Max
3800	Report	1 hr.	Max
3900	Report	1 hr.	Max
		6 Hrs.	

Adjust full rack to
67-68 lbs/hr. full flow rate

TABLE 11. Test Lubricant Properties

Oil SAE Vis. Grade		MIL-L-2104D 30	REO-203 30
Properties	ASTM Method		
K. Viscosity, 40°C, cSt	D 445	98.55	105
K. Viscosity, 100°C, cSt	D 445	11.36	11.8
Viscosity Index	D 2270	102	101
Flash Point, °C	D 92	223	241
Pour Point, °C	D 97	-17	-21
Total Acid No.	D 664	3.0	3.6
Total Base No.	D 2896	8.4	5.4
Carbon Residue		2.1	1.2
Sulfated Ash, wt%		0.84	0.93
Elemental Analysis, wt%	Method		
Ba	ICP	0.005	0.005
Ca	ICP	0.001	0.24
Mg	ICP	0.15	0.001
Zn	ICP	0.13	0.09
P	ICP	0.12	0.09
S	XRF	0.54	0.47
N	CLM	0.08	0.01

Both lubricants were chosen due to extensive experience in the particular engines and their wide acceptance as laboratory standard oils.

IV. RESULTS

A summary of the ten individual engine tests is shown in TABLE 12, and presented in this section; only significant wear or other abnormalities are discussed. Complete sets of the raw and calculated data are contained in the appendices. Following the individual test

TABLE 12. Army Engine-Fuel Test Summary

Engine	Test Fuel	Test Lubricant	Test Hours Completed/Cycle
GM 6.2L	Cat (1)	A(2)	210/CRC Wheel, Initial Baseline
GM 6.2L	Cat	A	210/CRC Wheel, Repeat Baseline
GM 6.2L	JP-8	A	210/CRC Wheel
GM 6.2L	JP-8	A	400/NATO AEP-5
Cummins NHC-250	Cat	A	210/CRC Wheel
Cummins NHC-250	JP-8	A	210/CRC Wheel
TCM LDT-465-1C	Cat	A	210/CRC Wheel
TCM LDT-465-1C	JP-8	A	210/CRC Wheel
DD 6V-53T	Cat	B(3)	240/CRC Track
DD 6V-53T	JP-8	B	240/CRC Track

(1) Cat is Reference No. 2 diesel fuel as specified in Section 5.2, Methods 354 and 355, FTMS 791C.
(2) Test Lubricant A is qualified MIL-L-2104D OE/HDO-30.
(3) Test Lubricant B is CRC REO 203 (SAE 30 Grade).

results, comparisons between the different tests are made that serve to summarize the results and establish the bases for the conclusions.

A. GM 6.2L, Initial Baseline Test Using Cat Diesel Fuel

The 210-hour test on the Cat reference diesel fuel was completed without any engine component failures. However, monitoring of the lubricant during the test indicated rapid thermal degradation of the oil and high concentrations of wear metals. These problems required several unplanned oil changes during the test in order to keep the oil below an extreme viscosity. The listing below indicates the test hour of oil change, as well as the oil viscosity, iron concentrations, TAN, and TBN recorded at each oil change:

Oil Change, hours	Viscosity at 100°C, cSt	Fe, ppm	TAN	TBN
0	11.04	Less than 10	2.51	6.49
70	64.83	360	9.56	0.50
126	70.59	330	7.80	0.39
182	49.08	230	5.85	1.87

In an attempt to correct the condition resulting in the rapid oil degradation, the following changes were made; the oil cooler was cleaned at 28 hours, the exhaust crossover pipe routed away from the oil pan at 126 hours of test time, and finally the maximum power condition was set according to fuel flow rate (67 to 68 lb/hr) rather than running against the factory set rack stop. The change in fuel flow rate resulted in less power output. Operating at the reduced power setting was begun at 190 hours of test time. The rapid viscosity increase of the oil indicated that it was being exposed to high temperatures. The exposure was occurring at a hot spot since the overall oil temperature remained at the set point of the temperature controller, 240°F. The effects of these changes are shown below as the rate of oil viscosity increase. These values were calculated by dividing the change in viscosity over the time interval following the modification.

Modification	Hours Test Time of Modification	Viscosity Increase, cSt/hr
Oil cooler cleaning	28	0.531
Exhaust pipe change	126	0.561
Reduced power setting	190	0.096

The modification of the test cycle was the only change made that significantly reduced the rate of oil deterioration. When the engine was disassembled at the conclusion of the testing, unusually high deposits were found on the underside of the pistons. These deposits indicated that this was the hot spot responsible for the rapid oil degradation. Reducing the maximum load setting lowered the piston temperature and the thermal stress on the oil that splashed on the piston underside. The average piston WTD rating for this test was 131, which is 45 percent higher than the result obtained for the Cat diesel fuel repeat test. The second baseline test is discussed in greater detail later in this section.

Figs. 5 through 7 show the fuel consumption versus test time, brake horsepower versus test time, and the brake specific fuel consumption versus test time. Fuel consumption declined slightly during the test due to wear in the pump. The step at 190 hours was due to the setting of the maximum power conditions by fuel flow rate, rather than rack stop.

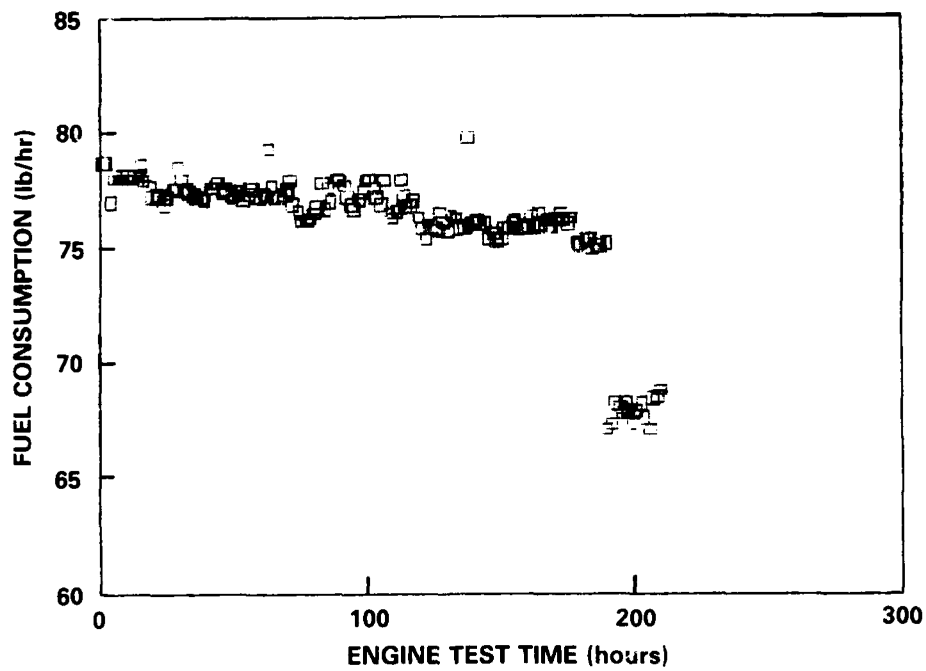


Figure 5. Fuel consumption versus test time, 6.2L/baseline

As shown in Fig. 6, power declined slightly, probably due to the lowered fuel delivery. The BSFC, as shown in Fig. 7, remained constant during most of the test. The slight upward trend in BSFC near the end of the test, while the fuel flow remained constant, cannot be conclusively explained. A similar trend, observed in the GM 6.2L JP-8 test, was attributed to fuel injection timing changes, which occurred as a result of pump drive shaft wear. As can be seen in Fig. 8, some pump shaft wear occurred during the Cat diesel fuel test. However, the wear was not as severe as that in the JP-8 test.

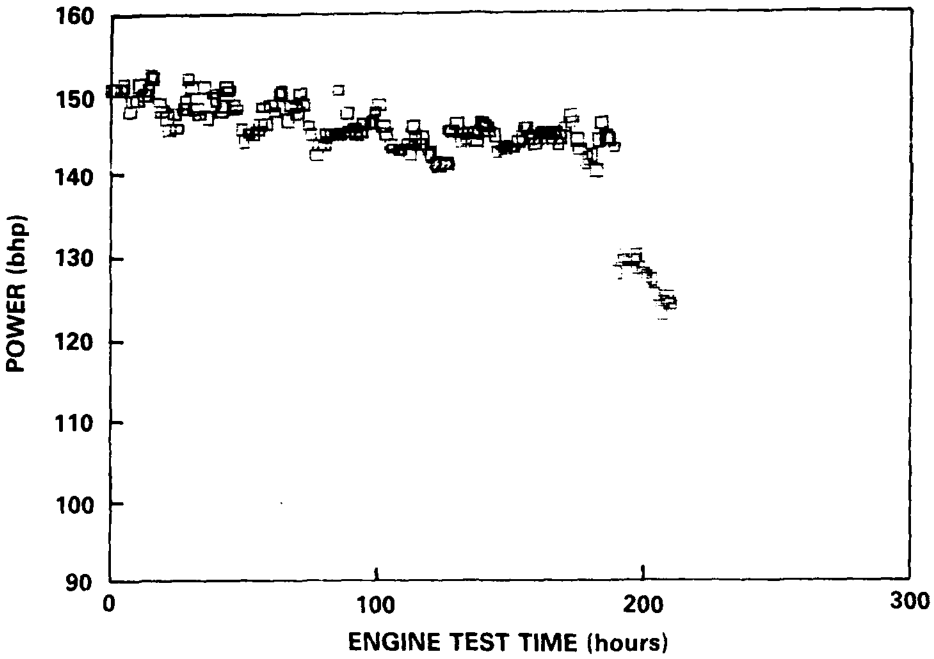


Figure 6. Brake horsepower versus test time, 6.2L/baseline

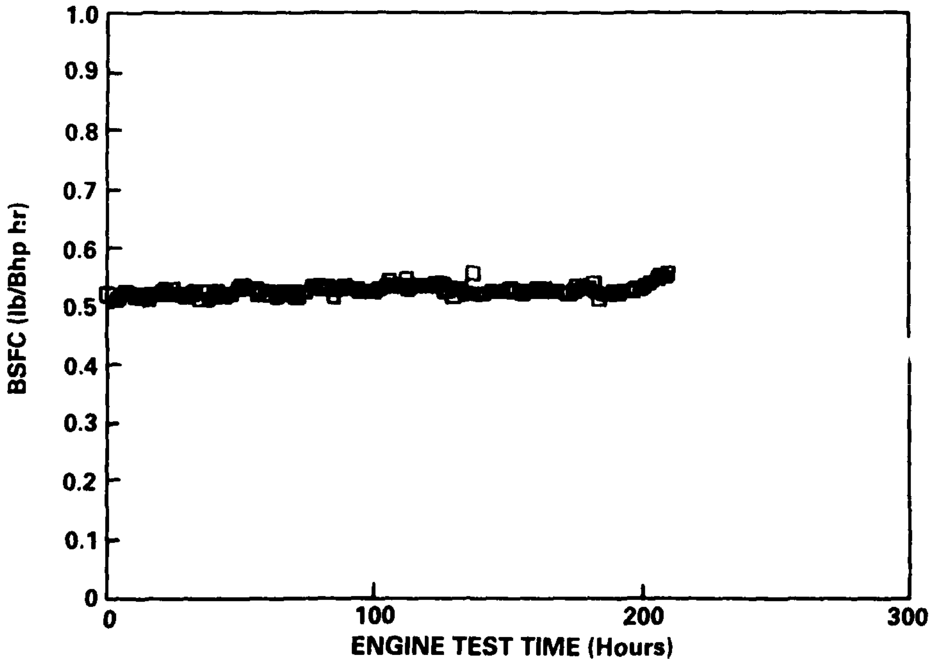


Figure 7. Brake specific fuel consumption versus test time, 6.2L/baseline

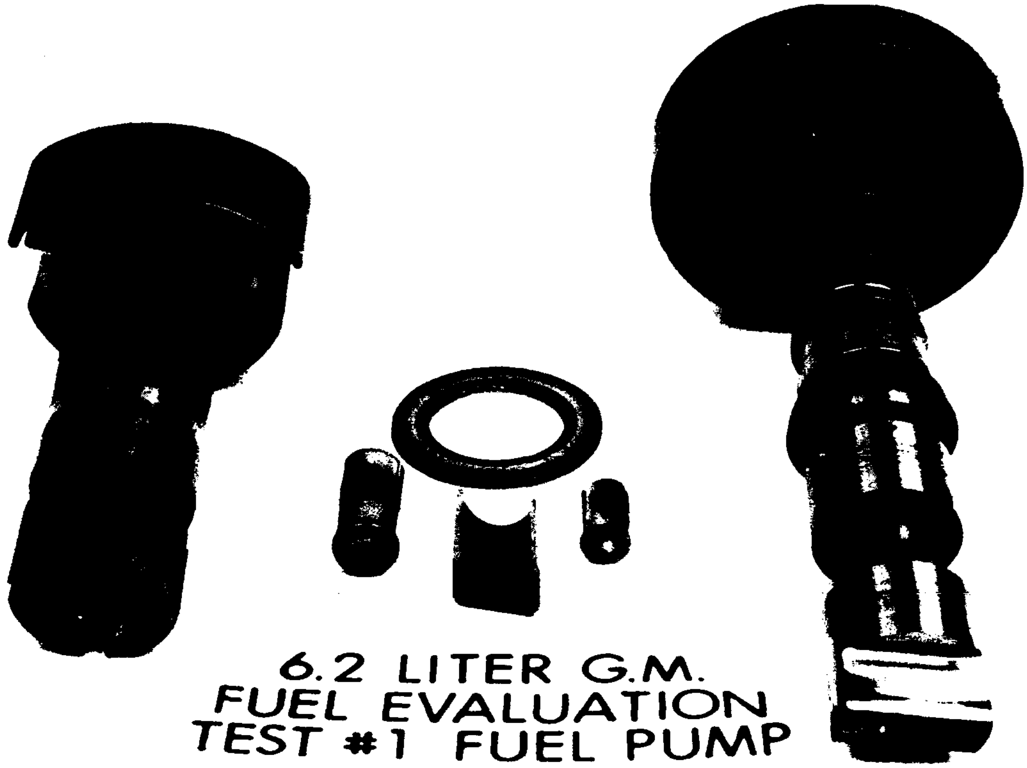


Figure 8. Photograph of fuel injection pump components

The only engine components that had unusual wear were the piston rings. Fig. 9 is a photograph of the most worn piston ring set. The barrel face of the top ring has been completely removed. It is apparent that the high iron concentration in the oil was due to the high ring wear, which is a consequence of high engine loading.

Due to the high rate of oil deterioration and the numerous changes made during the testing, it was felt that a good baseline set of data was not obtained. The high load factor of the test resulted in higher wear of critical engine components, increased rates of wear metals in the lubricating oil, and more deposits. Therefore, it was necessary to run a second baseline test. This first test was not used for comparison purposes.

B. GM 6.2L, Repeat Baseline Test Using Cat Diesel Fuel

The repeat test of the GM 6.2L engine, using Cat reference diesel fuel, was completed without any unusual problems. The high wear and oil thermal degradation observed

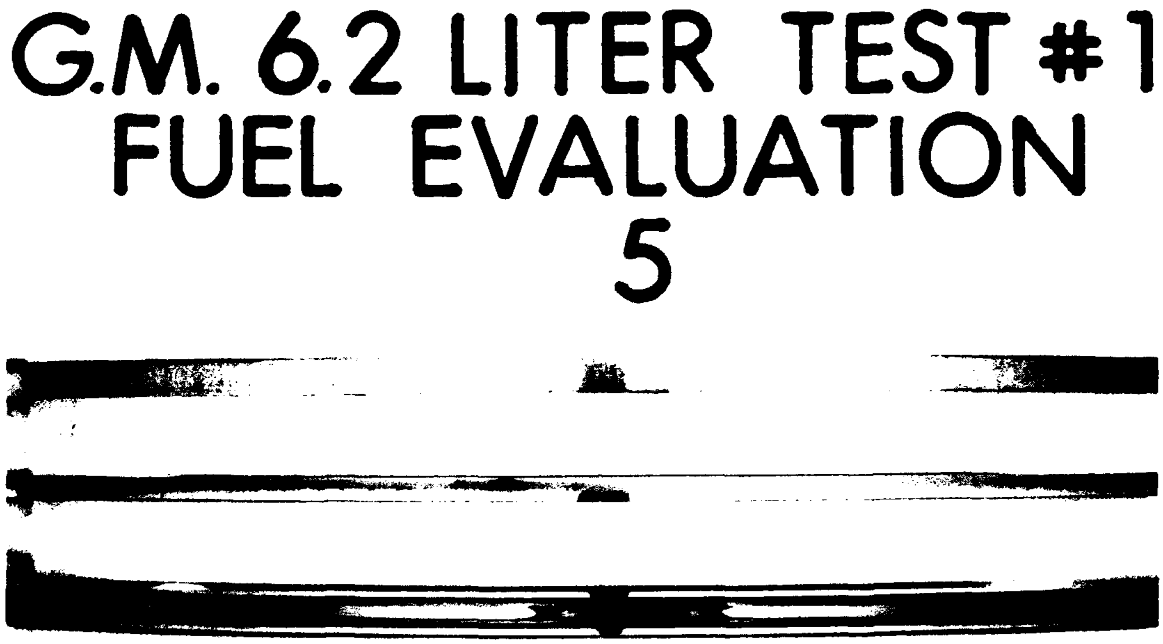


Figure 9. Most worn piston ring set

during the first test did not occur during this test. The reduced wear was due to the lower average fueling rate adopted for the second test.

During the first baseline test, the maximum power condition of the test cycle was set by running the fuel delivery rack against its stop. Near the end of the test, the practice of setting the maximum power condition by the fuel flow rate indicator was adopted. The average fuel flow rate was 76 lb/hr.

At the beginning of the second test, the engine was once again run against the rack stop. Fig. 10 shows the fuel consumption at the maximum power condition versus the test time, indicating that the fuel delivery was steadily increasing. Starting at 72 lb/hr, the fuel delivery increased to 75 lb/hr in 29 hours of the endurance test. At this point, the engine operators began setting the load condition according to the flow rate. Thus, the setting was 72 lb/hr.

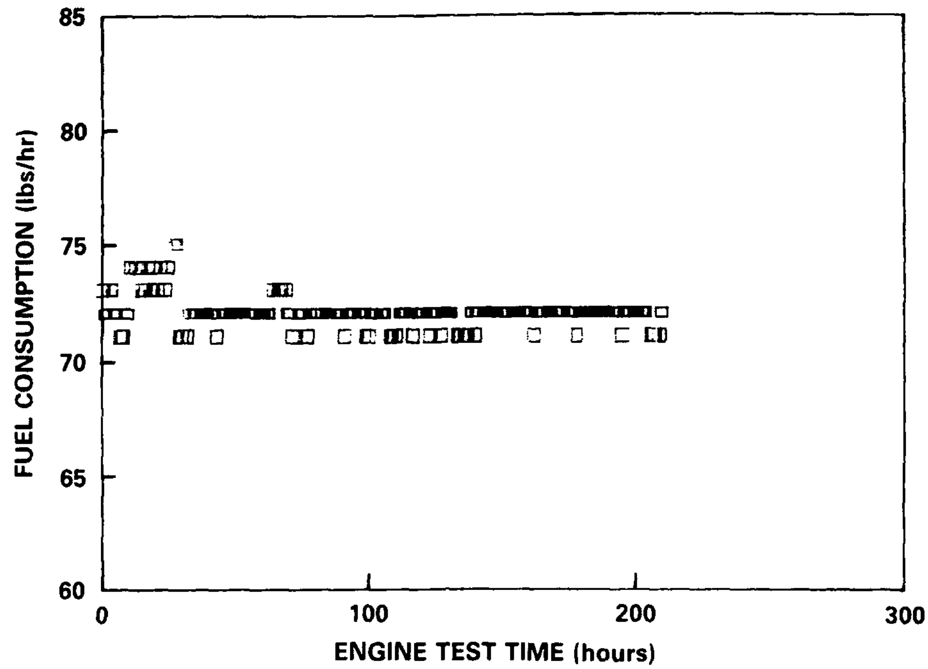


Figure 10. Fuel consumption versus test time, repeat 6.2L test

During the first test, the pump delivery was seen to decrease steadily. However, the second engine test showed the fuel delivery steadily increasing. Wear in the fuel injection pump can result in either an increase or decrease in fuel delivery, depending on the location of the wear in the pump.

Operating the engine at 5.3 percent less average fuel flow rate resulted in an anticipated loss of maximum power of 4.9 percent. The reduction in the maximum power setting had a dramatic effect on the wear of the engine. For example, the total iron accumulation in the oil decreased from 0.0075 to 0.0055 kg, representing a 26.6-percent reduction. The piston ring wear, as indicated by end gap increase, was reduced by 50 percent. Thermal oil degradation was significantly reduced, as no oil changes were necessitated by high oil viscosity. The previous test required three oil changes. The oil viscosity at the end of 210 hours was 21.97 cSt at 100°C. At the higher load condition of the first test, a similar viscosity of 25.52 cSt resulted after only 70 hours.

It was concluded that this engine's wear and level of lubricant stress are quite sensitive to the operating load. This sensitivity might be expected due to the engine's high rated output of 17.4 kW per liter displacement. Both the Cummins NHC-250 and the LDT-465 engines are rated at 13.3 kW/L. The high specific loading places greater stress throughout the engine; this stress in turn produces greater wear.

Similarly, the lubricant operates under higher pressure, temperature, and shear stress. There is also less lubricant capacity in the GM 6.2L engine than the other engines tested, which serves to further aggravate the problem. The GM 6.2L engine has 0.061 liter of oil per kW brake power compared to 0.112 kW/L for the NHC-250 and 0.204 kW/L for the LDT-465. Therefore, the oil in the GM 6.2L engine is exposed to the upper cylinder area more frequently, leading to thermal degradation. As a result, the concentration of oil contaminates from wear metals and blowby can be expected to rise faster since there is less oil diluting the contaminants. Although the GM 6V-53T engine is also highly stressed, it was not included in this discussion because it is a two-stroke type engine.

Although the repeating of the baseline diesel fuel test in the GM 6.2L engine was not part of the original test plan, useful experience was gained. Understanding the sensitivity of the engine to loading provides insight into interpreting the comparative fuel studies made in this study. Furthermore, it will become apparent that the type of test cycle and its severity can produce adverse wear effects that outweigh fuel effects.

C. GM 6.2L 210-Hour Test Using JP-8

The evaluation of JP-8 in the GM 6.2L engine encountered several unplanned events. These unscheduled events are listed in TABLE 13.

Fig. 11 shows the trends in the fuel consumption versus test time. During the first 32 hours, when the engine was run against the rack stop, the fuel delivery increased during this time, as it had done during the second baseline test. At 32 hours, the injectors were replaced, and the maximum load condition was set according to the fuel flow. The pump was replaced at 168 hours, and the maximum power test condition was set against the rack stop. Between 168 and 179 test hours, the power output increased as the fuel delivery increased, the same as had happened during the first hours of the test.

TABLE 13. GM 6.2L Engine Evaluation of JP-8

Test Hour	List of Unscheduled Events
32	• Injectors were changed in an attempt to correct increasing fuel flow and exhaust temperatures. • Test plan changed to setting maximum power point by fuel flow at 72-74 lb/hr rather than maximum rack stop.
97	• 2nd injector change. • Oil change.
168	• Replaced fuel injection pump. • Returned to setting maximum power condition by the rack stop.
179	• Set maximum power condition according to fuel flow.

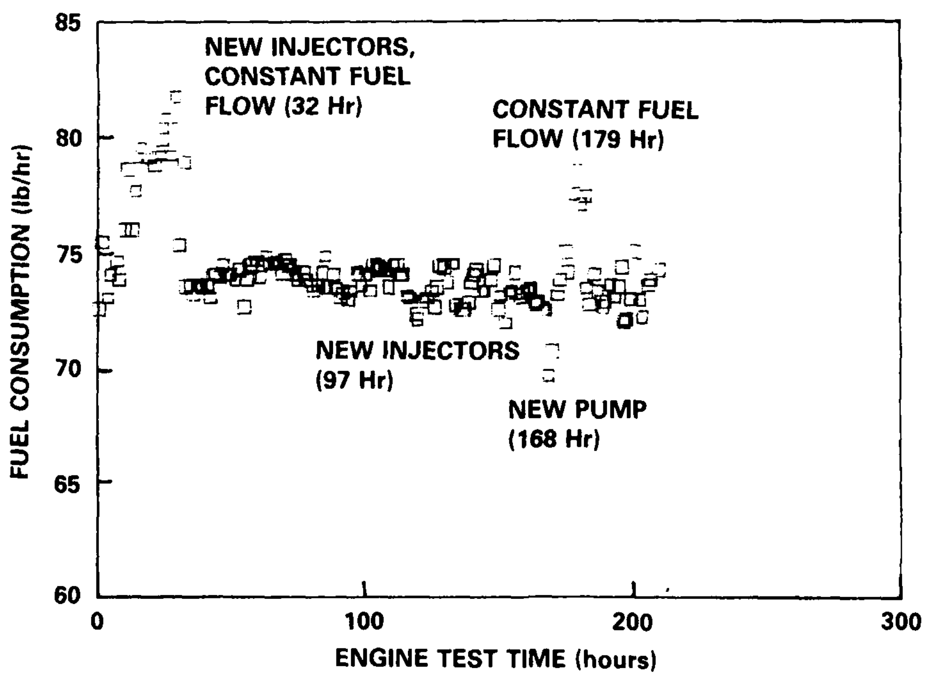


Figure 11. Fuel consumption versus test time, 6.2L/JP-8 Test

Fig. 12 shows these changes in the maximum power during the test cycle. Initially, the power increased as the fuel delivery increased. However, at 15 hours into the test, the power began to fall off, despite the increasing fuel flow. Power continued to decline after 32 test hours, when the fuel flow was held constant by the engine operator. Replacing the fuel injectors at 97 hours did restore some of the lost power but not completely. Finally, replacing the fuel injection pump brought the maximum power back up to the original level.

The brake specific fuel consumption (BSFC) is plotted in Fig. 13 for the 210-hour test. There was a steady decline in the efficiency of the engine through the test. Changing the injectors at 32 hours test time did not improve the BSFC. However, the injector change at 97 hours slightly improved the efficiency of the engine. The original BSFC was restored when the injection pump was replaced. Thus, the engine itself was not affected by the fuel since the performance and efficiency returned following replacement of the pump.

D. GM 6.2L 400-Hour Test Using JP-8

The GM 6.2L engine was tested on JP-8 fuel, in accordance with the NATO Standard Diesel Engine Test Procedure AEP-5. During the 400-hour NATO cycle test, the maximum brake horsepower declined 7.2 percent, as shown in Fig. 14. The average fuel flow rate, however, remained fairly constant over the 400 hours as shown in Fig. 15. The operator set the maximum power condition by setting the pump against the rack stop. Operating in this mode had resulted in steadily increasing fuel delivery during previous endurance tests. However, no problem of this kind was observed during the 400-hour test.

As a result of the declining power, the BSFC, as plotted in Fig. 16, rose 7.3 percent during the test. The changes in efficiency were reflected in the exhaust temperature common to the cylinders, shown in Fig. 17.

Comparison of the fuel injector and pump tests performed before and after the 400-hour test did not indicate any significant changes. The drop in pop-off pressure is typical. Disassembly of the pump did reveal some significant wear on the drive shaft tang as shown in Fig. 18. This is the same wear as seen in the previous 210-hour JP-8 test;

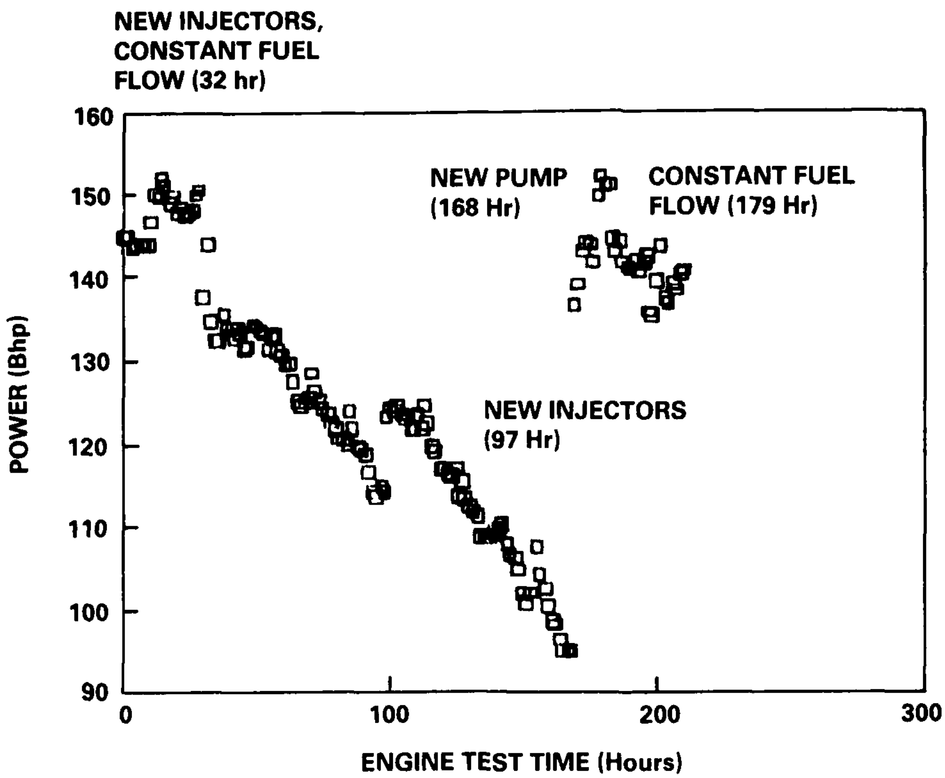


Figure 12. Maximum power versus test time, 6.2L/JP-8 test

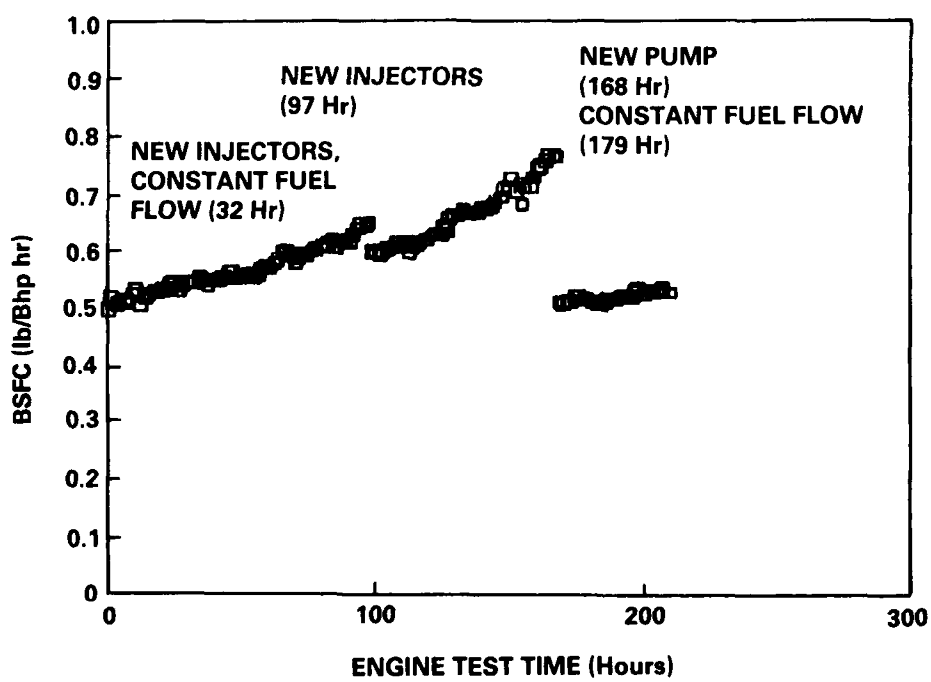


Figure 13. Brake specific fuel consumption versus test time, 6.2L/JP-8 test

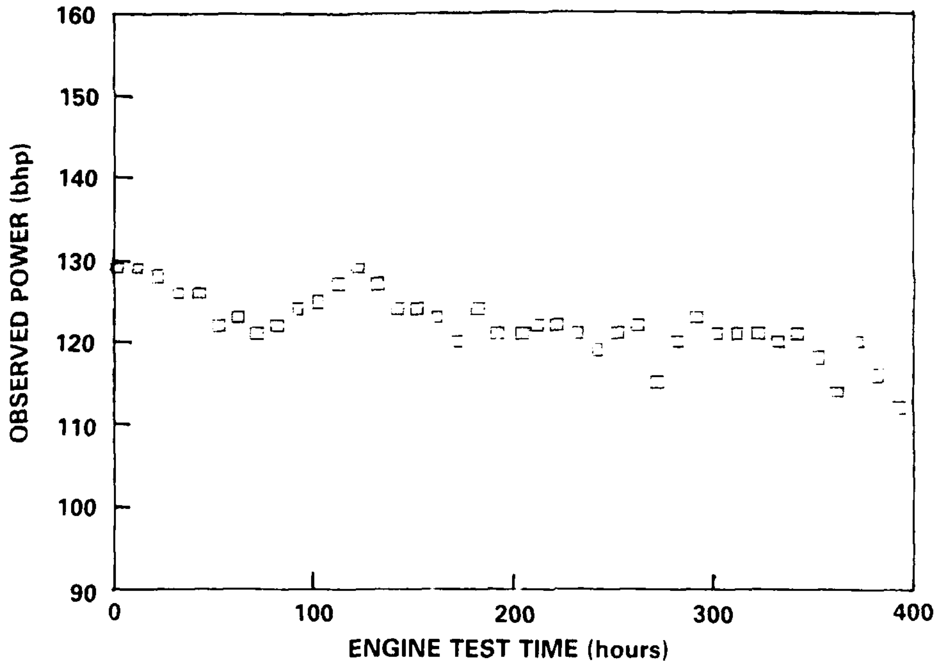


Figure 14. Maximum power versus test time, 6.2L/JP-8 400-hour test

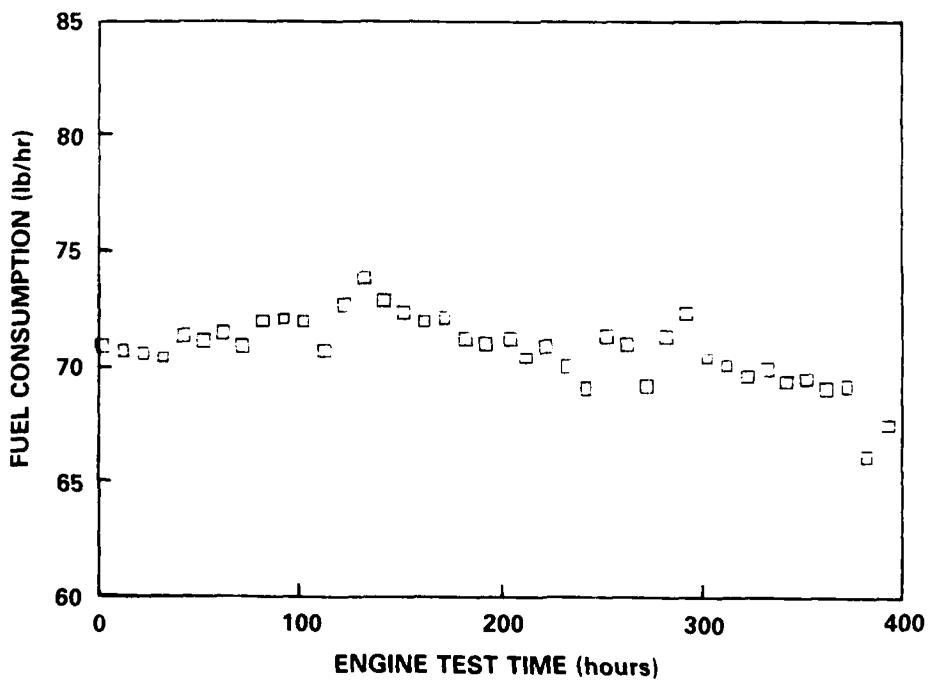


Figure 15. Fuel flow rate versus test time, 6.2L/JP-8 400-hour test

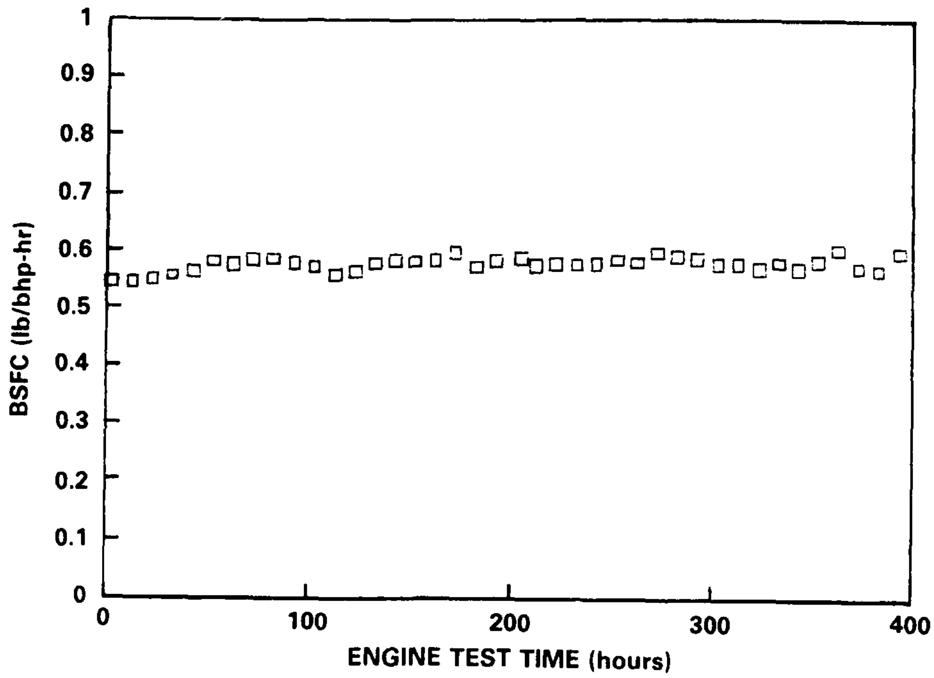


Figure 16. Brake specific fuel consumption versus test time, 6.2L/JP-8 400-hour test

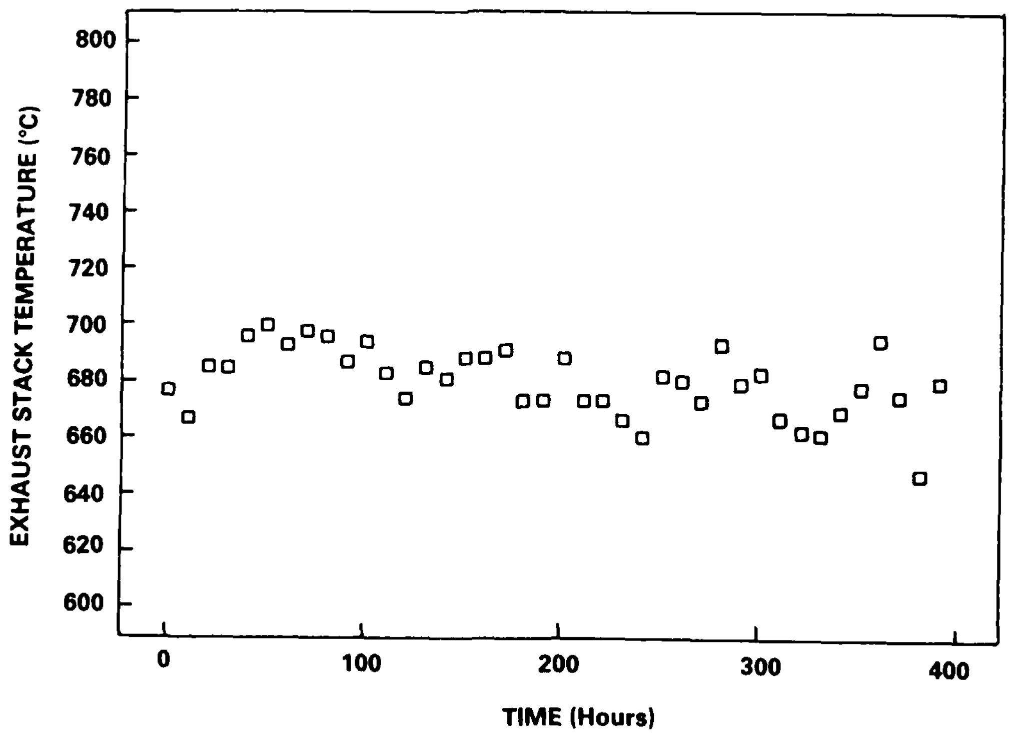


Figure 17. Exhaust gas temperature versus test time, 6.2L/JP-8 400-hour test

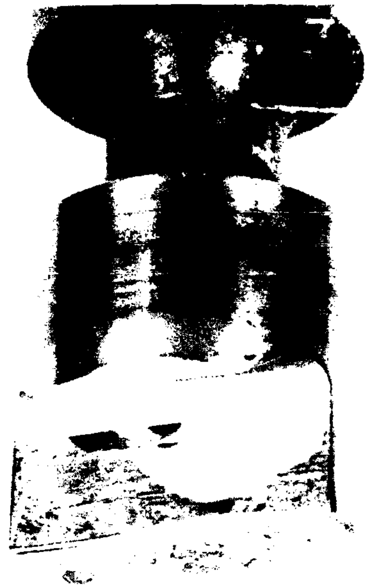


Figure 18. Photograph of injection pump drive shaft, 6.2L/JP-8

however, the 400-hour test did not produce as severe a wear scar. This drive tang is a fuel-wetted component.

The difference in the amount of drive shaft wear between the tests may be attributed to two factors; the higher load factor of the 210-hour cycle, and the inlet fuel temperature effect on the fuel viscosity. Also considered as another possibility but dismissed, was fuel lubricity. Ball-on-Cylinder machine (BOCM) measurements made during the 400-hour test were the same as the earlier 210-hour test. The JP-8 produced a BOCM wear scar of 0.32 to 0.34 mm diameter. Such a scar measurement indicates that the fuel lubricity could be a contributing factor to the pump wear. However, since it was the same during both the 210- and 400-hour tests, it cannot explain why the 210-hour test produced more wear.

Other possible explanations are that the 210-hour test cycle is more severe than the 400-hour test, or the fuel temperature and its effect on fuel viscosity resulted in the different wear results of the fuel pumps during the two tests.

The 210-hour cycle contains 150 hours of full-speed and maximum power operation as opposed to 128 hours during the 400-hour NATO endurance cycle. The maximum load

condition presents the greatest loading on the fuel pump, generating the most wear. However, the difference between the two cycles does not appear to be large enough to be significant.

The average inlet fuel temperatures differed during the 210- and 400-hour tests. The inlet fuel temperature for the NATO cycle was 84°F (28.8°C) and the temperature for the 210-hour cycle was 105°F (40.5°C). Fig. 19 is a viscosity versus temperature plot for the JP-8 used during these tests. From this plot, the fuel viscosity for the NATO test can be found to be 1.50 cSt and for the 210-hour test, 1.27 cSt. General Motors cautions against the use of fuel in the pump having viscosity below 1.50 cSt.

It would appear that the combination of the higher loading and lower fuel viscosity resulted in the abnormal pump wear for the 210-hour test, as compared to the 400-hour NATO cycle test. As a result of these tests, subsequent experiments were conducted with fuel injection systems in bench tests (18) and full-scale vehicle tests (19). The injection pump wear identified was confirmed to be increased by both low fuel viscosity and high injection rates in the bench tests. However, field testing for 10,000 miles failed to produce any 6.2L engine pump wear for JP-8 compared to DF-2-fueled vehicles.

Disassembly of the engine did not reveal any unusual wear. The used oil analysis indicated that the wear metals, notably iron, were accumulating at half the rate as that observed during the 210-hour test. This decreased rate would be due to the difference in the engine loading.

E. Cummins NHC-250 210-Hour Test Using Cat Diesel Fuel

The 210-hour Cummins NHC-250 engine test using the baseline Cat reference fuel was completed without any significant problems. No changes were detected in the engine itself or the fuel injection system.

Fig. 20, the plot of fuel consumption versus test time, shows that no long-term changes occurred in the fuel flow. Pump calibration data (in Appendix E) confirmed the engine test data.

Fig. 21, the power produced during the maximum power test condition, indicates that the engine power did not vary during the test. As a result, the BSFC, plotted versus test time, in Fig. 22, did not change during the test.

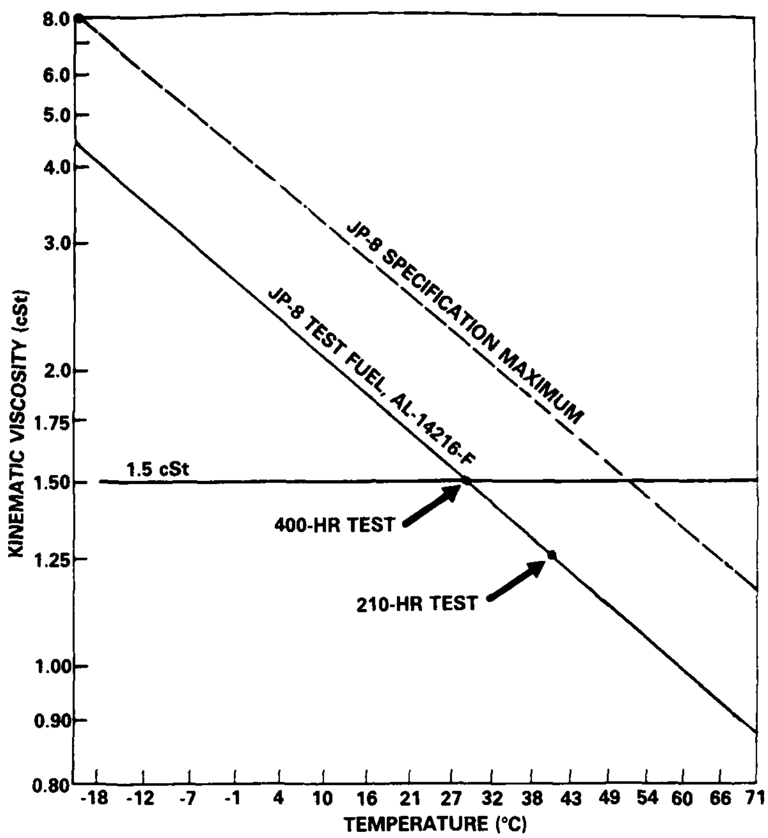


Figure 19. Kinematic viscosity of JP-8 versus temperature

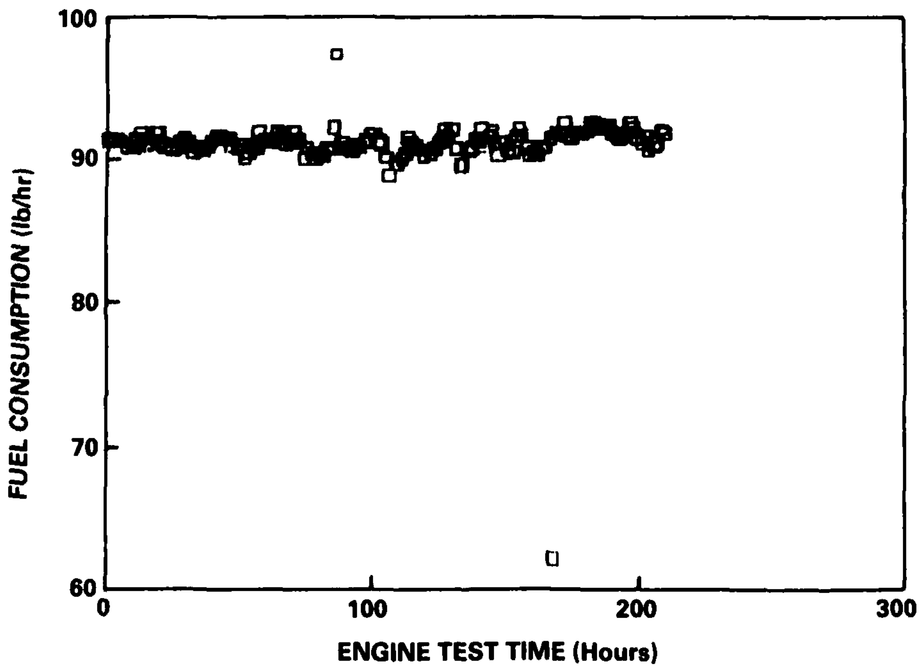


Figure 20. Fuel consumption versus test time, NHC-250/baseline

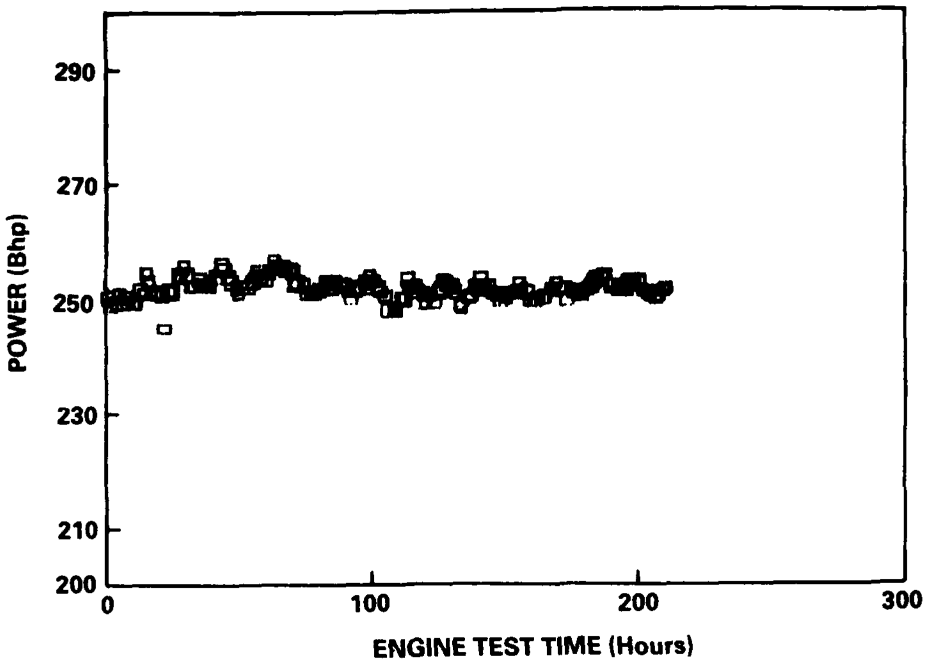


Figure 21. Maximum power versus test time, NHC-250/baseline

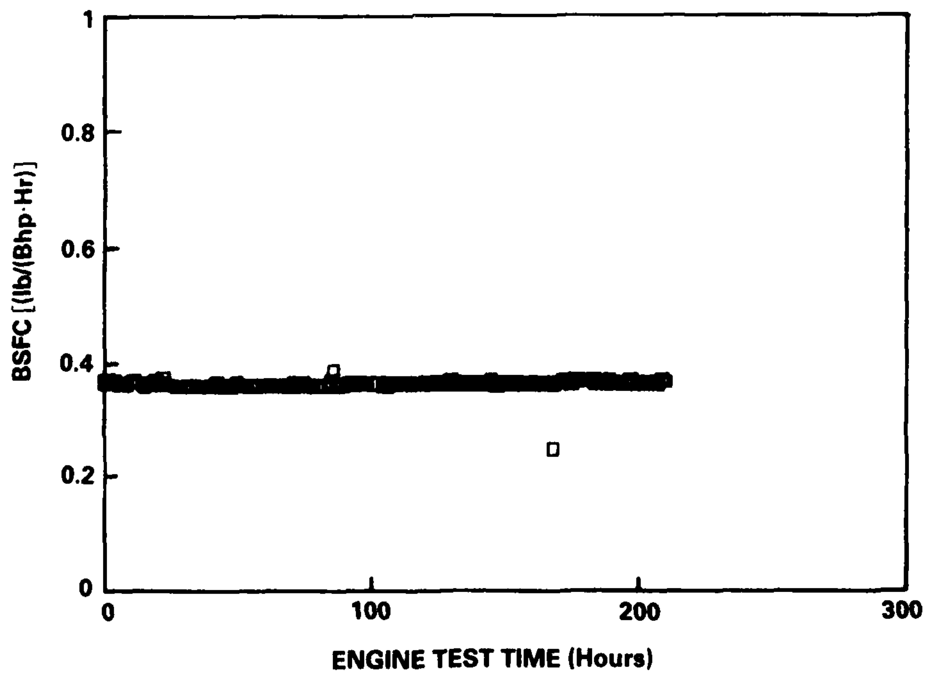


Figure 22. Brake specific fuel consumption versus test time, NHC-250/baseline

F. Cummins NHC-250 210-Hour Test Using JP-8

During the test of the Cummins NHC-250 using JP-8, no unusual events occurred. However, differences in the pre- and post-engine measurements and the used oil analysis indicated that greater wear occurred during the JP-8 test. The fuel consumption versus the test time is plotted in Fig. 23. The maximum fuel delivery was 92 lb/hr at the start of the test, and it quickly rose to 95 lb/hr at 25 hours of test time. Between 25 hours and the conclusion of the test, the maximum fuel delivery increased to 97 lb/hr. The maximum fuel delivery for this engine depends on the pressure output of the fuel pump. The pressure, in turn, is determined by a speed governor, which is a fuel-wetted mechanism. Therefore, the increased fuel delivery observed during the test may be a fuel effect. The fuel delivery did not increase during the baseline test. The overall engine performance did not change during the endurance test as seen by the BSFC versus test time plot in Fig. 24. The BSFC remained constant throughout the test.

Fig. 25 is a photograph of the injection gear pump. This gear pump develops fuel pressure, which is regulated by the governor mechanism. No unusual wear was observed. Likewise, photographs of the engine parts and injector pins do not indicate any abnormal wear.

G. LDT-465-1C Engine 210-Hour Test Using Cat Diesel Fuel

No unusual problems arose during the baseline test of the LDT-465-1C engine. As in the case of the Cummins engine, little change occurred in the engine measurements. The average change in the ring end gap was 0.0005 inches (0.0127 mm), which is well within the variation due to measurement errors. Therefore, greater importance should be placed on the wear metals in the lubricant.

H. LDT-465-1C Engine 210-Hour Test Using JP-8 Fuel

Again, the LDT-465-1C engine ran reliably on JP-8 fuel with no fuel-related problems apparent during the test. As discussed in more detail in the comparisons section, the wear in the engine upper cylinder area was less than with the Cat fuel. Also, the engine oil was not as stressed during this test.

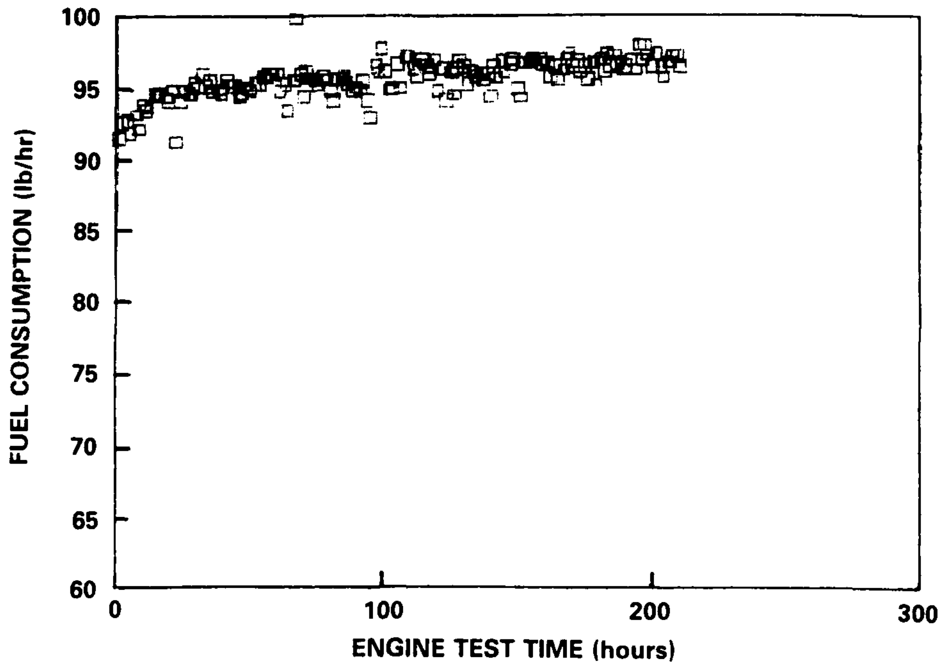


Figure 23. Fuel consumption versus test time, NHC-250/JP-8

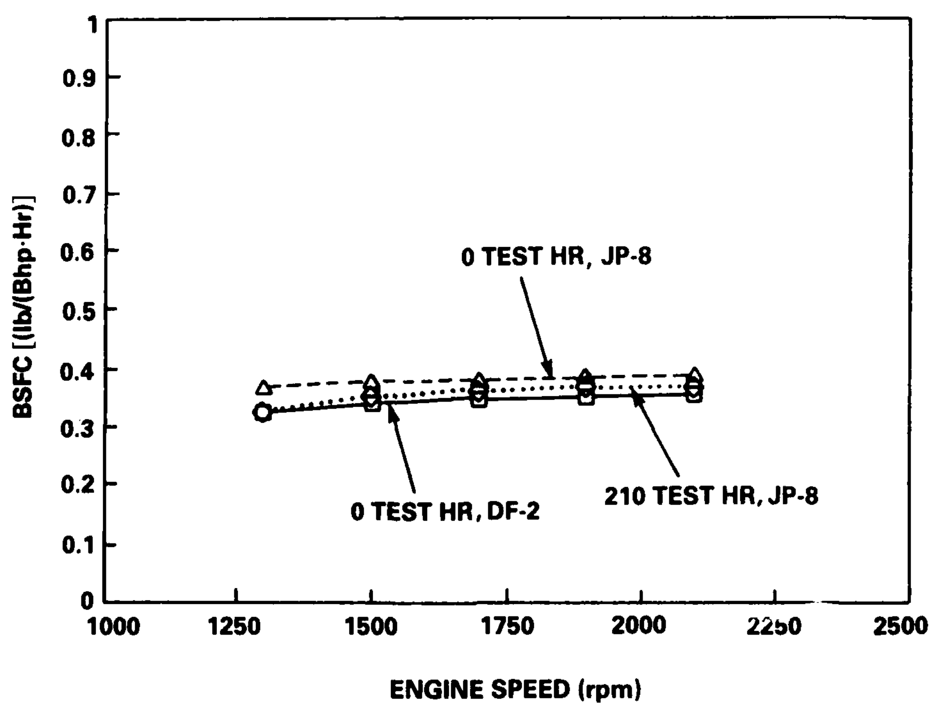


Figure 24. Full load brake specific fuel consumption curves, NHC-250/JP-8

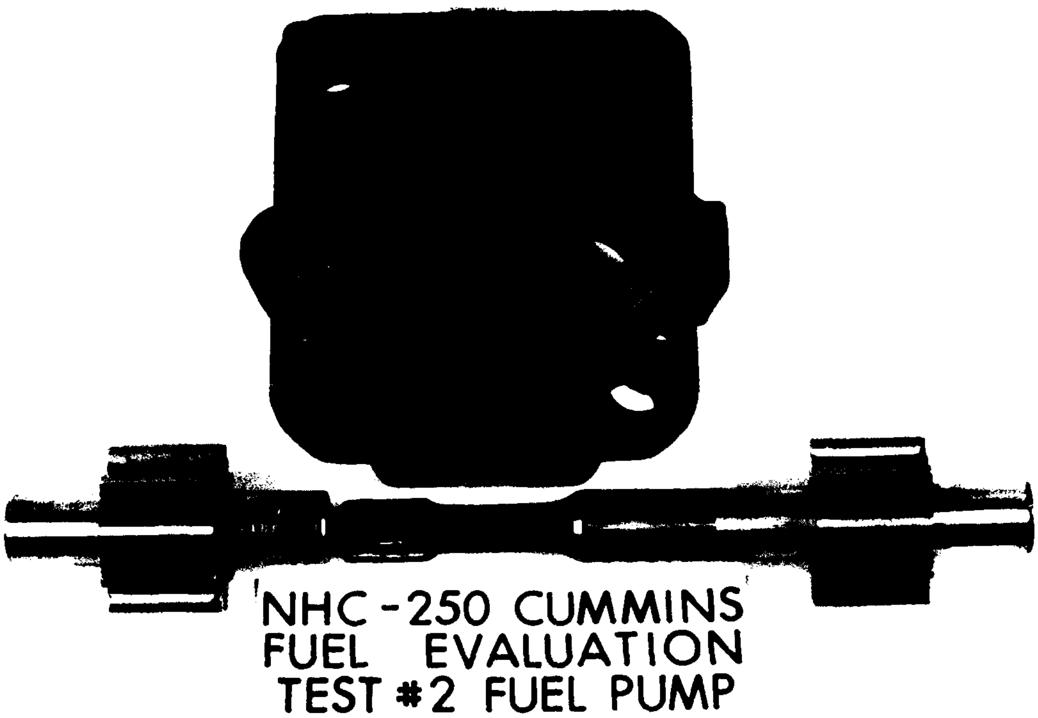


Figure 25. Photograph of injection pump gears, NHC-250/JP-8

I. GM 6V-53T Engine Operating on Cat Diesel Fuel

The baseline test using the Cat reference fuel was successfully completed in the GM Detroit Diesel (DD) 6V-53T engine. It was, however, necessary to replace the No. 2 cylinder on the right side at 40 hours into the endurance cycle test. The replacement of one cylinder kit is allowed in the test procedure if a high degree of scuffing is found by inspection using a bore scope. This provision is included in the procedures since the 240-hour tracked vehicle cycle stresses the engine near the maximum of its operating limitations.

J. GM 6V-53T Engine Operating on JP-8 Fuel

No unusual problems were encountered in operating the GM DD 6V-53T engine on JP-8 fuel during the 240-hour tracked vehicle cycle. As discussed in the Comparative Results section, differences in performance between Cat fuel and JP-8 were observed.

K. Comparative Results Between Cat Diesel Fuel and JP-8 Fueling

The details of specific problems that arose during the individual engine tests are discussed in previous sections. In this section, comparisons are made between the base fuel and JP-8 engine performance and durability. The comparisons are based on the engine power, fuel consumption, thermal efficiency, specific volumetric consumption (vehicle range), wear and engine lubricant analysis.

1. Engine Performance

Various properties of JP-8 fuel can be expected to result in reduced power output. Fig. 26 illustrates the difference in maximum power developed between JP-8 and the Cat fuel for the four engines. The results are presented as the percent change from the baseline diesel engine performance. The maximum power developed by the GM 6.2L engine was reduced 11.2 percent, which represented the greatest power loss of the four engines. The LDT-465 engine actually gained power. The power increase was, as will be shown, due to both an increase in efficiency of the engine and increased fuel flow rate due to the automatic fuel density compensator incorporated into the Army's multifuel engine. The NHC-250 engine's power loss was near zero. Again, this was due to some compensation for the lower fuel density and viscosity of the PT (pressure-time) fuel injection system. The power loss of the 6V-53T engine was as expected for the uncompensated high-pressure fuel injection system.

The variations in the fuel delivery are shown in Fig. 27. The GM 6.2L and DD 6V-53T fuel flow rates are less than the baseline Cat fuel tests for the respective engines. The Cummins PT system's partial compensation minimized the loss, whereas the LDT-465 engine tended to over compensate. The resultant fuel flow for the LDT-465 was 2.5 percent higher than the JP-8 fuel. The differences between the engines represent the response of the various fuel injection systems. The high-pressure systems, such as the 6V-53T and the rotary distribution pump of the GM 6.2L. incurred the highest loss of fuel delivery due to JP-8's lower viscosity.

Although the Cummins PT system is not specially designed as a compensating system, it does tend to increase the fuel injected as the fuel viscosity drops. The metering principle is based on fuel flowing through an orifice. A gear-type pump develops a

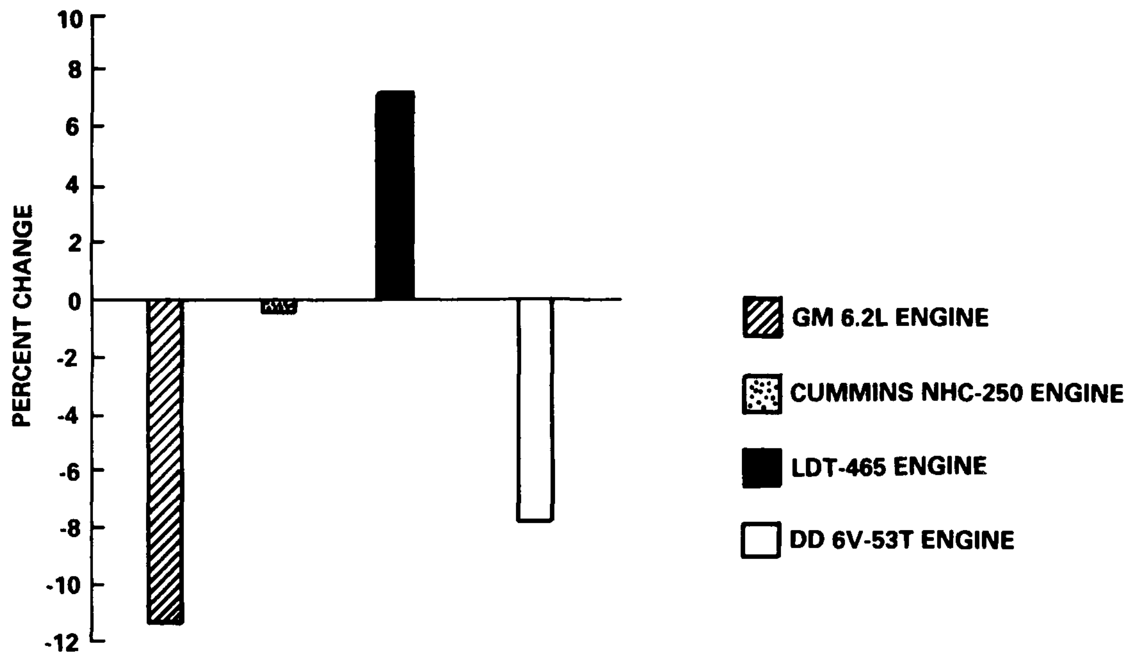


Figure 26. Percent change in the maximum power

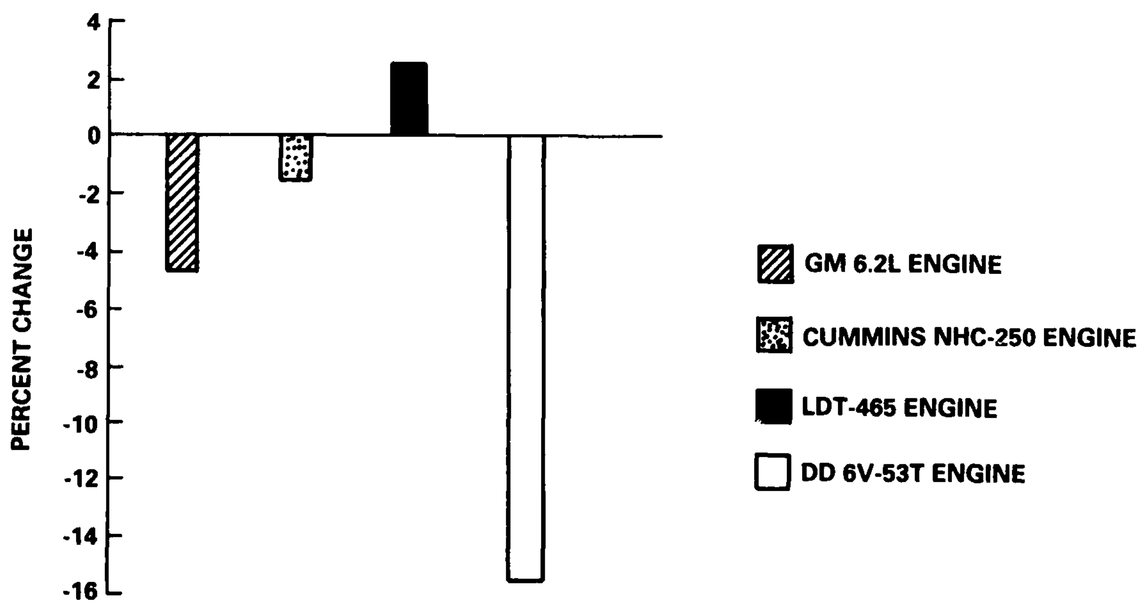


Figure 27. Percent change in the volumetric fuel flow at the maximum power condition

regulated metering pressure. The regulator output pressure is determined by the speed governor. The quantity of fuel metered at each injector is determined by the flow across an orifice in the time available between engine cycles. If a lower viscosity fuel is used, the regulated pressure should remain unchanged due to the regulator action (unless the viscosity is so low that the gear pump cannot develop sufficient pressure). The flow through the orifice will increase, however, due to the lower viscosity.

The LDT-465 engine is equipped with a density compensator. As the density of the fuel decreases, the maximum fuel delivery is automatically increased. With the use of the JP-8 fuel, the mechanism over compensated, increasing the fuel flow beyond the Cat setting. The pump itself is a rotary distribution type. The maximum fuel stop must have been raised considerably since no effect of the low viscosity, which dropped the fuel delivery of the 6.2L, is apparent.

The fuel delivery of the 6V-53T engine was substantially reduced while using JP-8 fuel. This engine has the highest pressure injection system tested. The high pressures are necessary to produce a fine atomization for use in the quiescent open combustion chamber.

The effects of JP-8 on the thermal efficiencies of the engines at maximum power are illustrated in Fig. 28. The thermal efficiencies of all the engines was increased except for the GM 6.2L engine. The LDT-465 engine demonstrated a remarkable increase of nearly 10-percent improvement. The efficiency improvements shown in this test served to offset the fuel's lower heating value and detrimental leakage effects of the engine fuel pump. The effects are due to better atomization and higher evaporation rates due to the lower boiling range of the JP-8. This is particularly true in the case of the LDT-465, which being of the MAN design, depends on fuel evaporation from the piston surface for combustion rate control. Faster burning results in increasing efficiency as the thermodynamic ideal of constant volume combustion is approached.

The net effect of the changes in thermal efficiency and the lower volumetric heating value of JP-8 resulted in improvements in the BTU per horsepower-hour of the engines. This factor would result in increased projected "vehicle range." The changes in the specific volumetric fuel consumption are given in Fig. 29. Again, these comparisons are made at the maximum power condition. The effects on the NHC-250 and 6V-53T engines were slight. On the other hand, a significant improvement of 7.4 percent was evident for

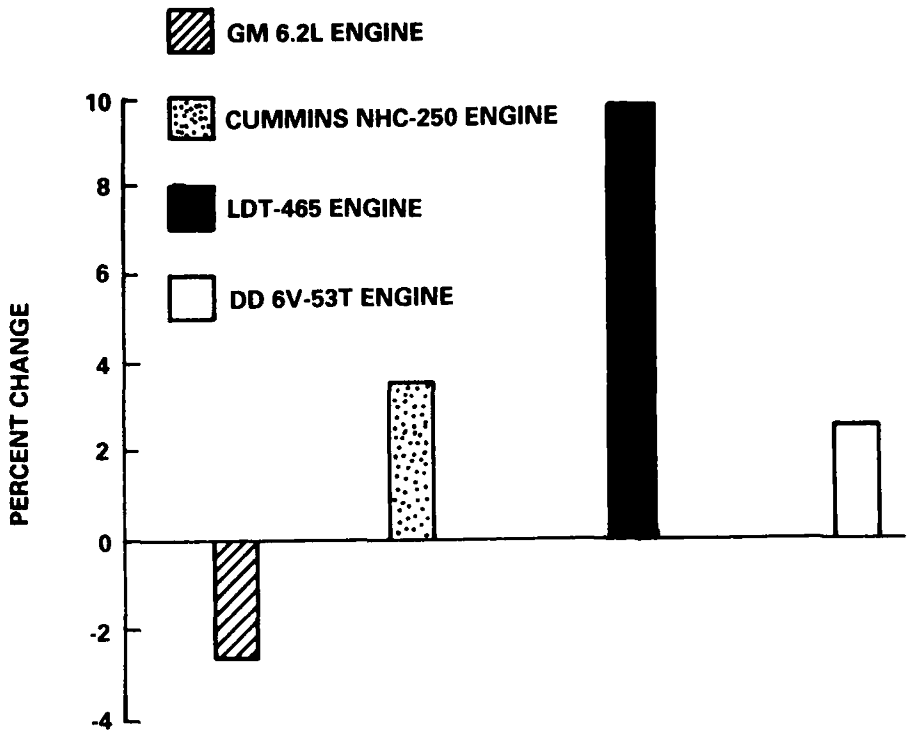


Figure 28. Percent change of thermal efficiency

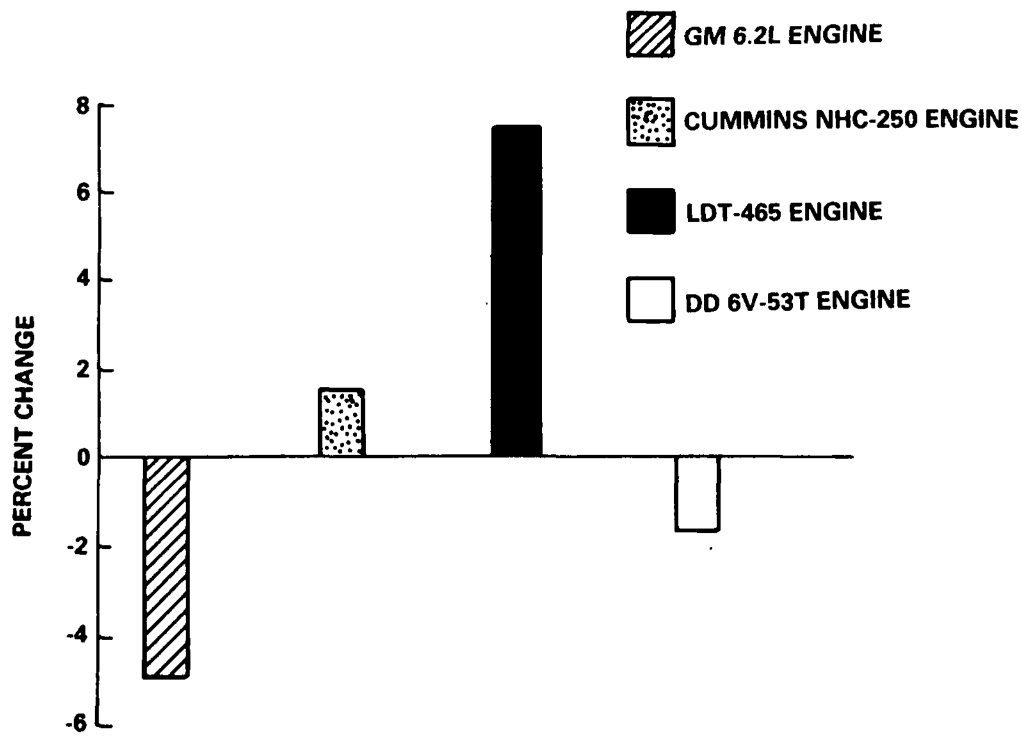


Figure 29. Percent change in projected vehicle range

the LDT-465 engine. The GM 6.2L engine suffered a 5-percent loss in projected vehicle range. These comparisons were made at the maximum power condition since the data were available.

2. Fuel Consumption Comparison

However, vehicles rarely operate at maximum power continuously. A better projection of vehicle range could be made using engine dynamometer results at partial load settings. Special fuel consumption tests were conducted at partial load using a GMC 6V-53N engine. This test was conducted at a different time than the endurance tests, and as a result, a different engine was used. A 25-point matrix was run that included five loads at each of five speeds. The full-load points at each speed were run against the rack stop for both DF-2 (Cat fuel) and JP-8 fuels. However, the partial-load points for JP-8 were run at DF-2 equivalent power levels. This procedure simulated a vehicle operator extracting the same level of vehicle performance with JP-8 during part-load operation. TABLE 14 lists the changes in engine response with JP-8. The averaged partial load volumetric fuel consumption shows a 2.3-percent increase using JP-8. This increase corresponds to the 2.3-percent lower volumetric net heat of combustion of the JP-8. Thus, for the Detroit Diesel 6V-53N, overall partial-load volumetric fuel consumption increases with JP-8 can be predicted by the change in the volumetric net heat of combustion from that of DF-2. The thermal efficiency data show that the thermal efficiency improvements seen at full loads and the lower speeds with the Detroit Diesel 6V-53N engine are not seen at partial loads.

The power and thermal efficiency changes at full rack are shown in Fig. 30. The data show JP-8 operation provides a 1.5-percent improvement in brake horsepower at 1400 rpm, along with an 8.8-percent gain in thermal efficiency. The increase in power at 1400 rpm may be attributed to a fuel combustion timing effect. Thermal efficiency gains in engines have been attributed to fuels that exhibit larger amounts of constant volume combustion. Increased premixed combustion, which generally denotes a more constant volume combustion, is associated with fuels that have lower cetane numbers. The cetane number for the JP-8 used was 41, compared to 52 for the DF-2. As the engine speed increased, the timing effects for optimum combustion with JP-8 diminished, and the increases in thermal efficiency declined. These factors, along with the 8.5-percent average heat addition losses due to injection system leakages, resulted in a decrease of available full-load power at the engine's rated speed of 2800 rpm. The results at the maximum power and rpm condition agree with those obtained for the turbocharged version of this engine that were presented earlier.

TABLE 14. Detroit Diesel 6V-53N Performance Deviations Using JP-8

	Cat Fuel, DF-2		JP-8 Performance, as Percent of DF-2							
Speed, rpm	Load, lb-ft	Mass Fuel Flow, lb/hr	Load, Δ%	Mass Fuel Flow, Δ%	Power, Δ%	BSFC, Δ%	Vol. Fuel Flow, Δ%	BSVC, Δ%	Eff., Δ%	Heat, Δ%
	403.7*	57.3	1.5	-7.5	1.5	-8.8	-4.6	6.2	8.8	-6.7
	322.9	35.0	0.0	-0.6	-0.1	-0.5	2.6	-2.7	-0.3	0.5
1400	242.2	26.4	0.1	0.4	0.0	0.2	3.8	-3.4	-1.2	1.3
	161.4	19.4	0.1	1.5	0.2	1.1	4.7	-4.3	-2.3	2.3
	80.7	13.3	-0.1	-0.8	0.0	-0.8	2.1	-2.4	-0.4	0.0
	440.0*	68.8	-1.8	-10.6	-1.8	-9.0	-7.7	6.4	8.9	-9.8
	352.0	47.0	0.1	-1.9	0.2	-2.1	1.2	-1.1	1.1	-1.0
1800	262.0	35.6	0.0	-2.2	0.0	-2.0	1.0	-0.9	1.4	-1.4
	176.0	26.8	0.0	0.7	0.0	0.9	4.0	-3.8	-1.6	1.6
	88.0	18.1	0.0	2.2	0.0	2.2	5.5	-5.2	-3.0	3.1
	445.0*	77.5	-5.1	-9.5	-5.0	-4.8	-6.7	1.6	4.2	-8.7
	356.0	58.0	0.0	-2.1	0.0	-2.1	1.1	-1.0	1.1	-1.2
2200	267.0	44.8	0.0	-0.7	0.0	-0.7	2.5	-2.4	-0.3	0.2
	178.0	33.5	0.0	-2.1	0.0	-2.0	1.1	-1.0	1.3	-1.2
	89.0	23.4	0.0	-1.7	0.0	-1.8	1.5	-1.4	0.9	-0.8
	427.0*	83.5	-7.0	-9.2	-6.9	-2.7	-6.4	-0.6	1.8	-8.5
	341.6	65.1	0.0	1.1	0.0	1.2	4.4	-4.1	-2.0	2.0
2500	256.2	51.6	0.0	-3.1	0.0	-3.1	0.0	0.0	2.4	-2.2
	170.8	38.6	0.0	-3.1	0.0	-3.2	0.0	-0.1	2.1	-2.2
	85.4	26.8	0.0	-0.4	0.0	-0.3	2.9	-2.8	-0.5	0.5
	398.0*	89.2	-7.8	-9.2	-7.7	-1.4	-6.3	-1.5	0.9	-8.5
	318.4	70.6	0.0	-0.6	0.2	-0.7	2.6	-2.3	0.0	0.1
2800	238.8	56.7	0.0	-2.5	0.0	-2.5	0.6	-0.6	1.6	-1.6
	159.2	43.4	0.0	-0.7	0.0	-0.6	2.5	-2.5	-0.4	0.2
	79.6	31.6	0.0	-1.9	0.0	-2.0	1.1	-1.3	1.1	-1.0

* Full-load conditions.

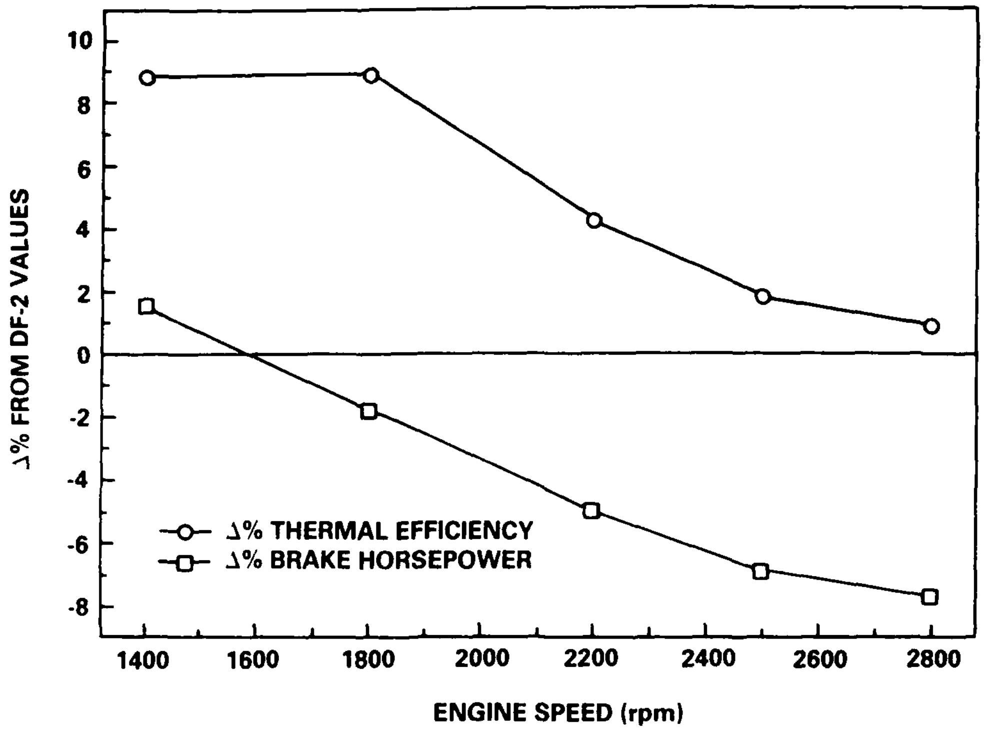


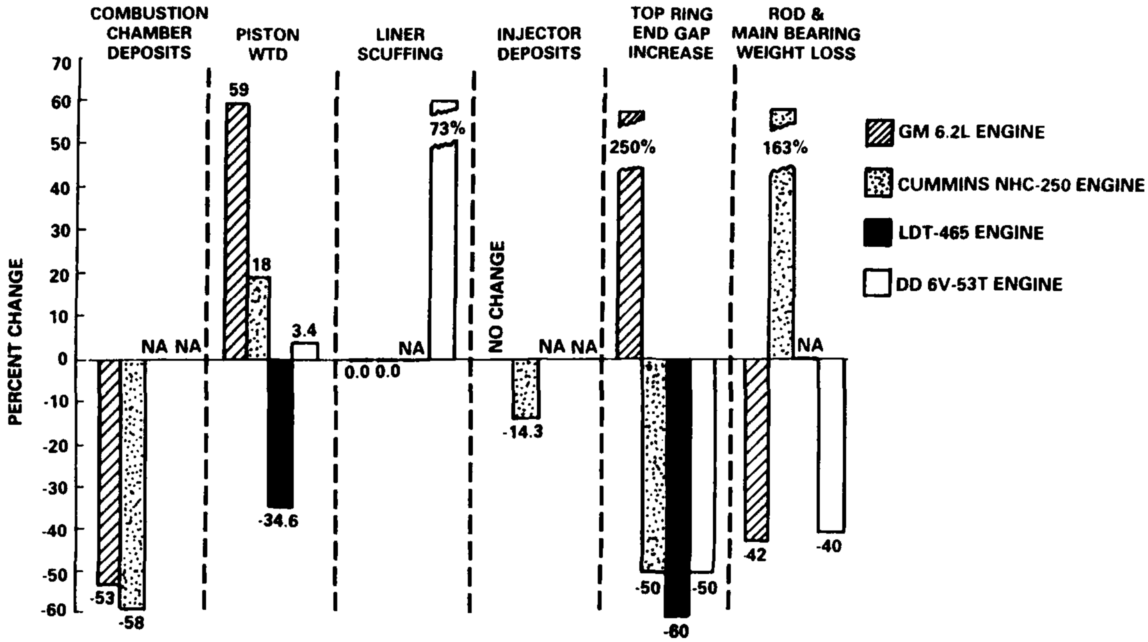
Figure 30. Detroit Diesel 6V-53N full-load response to JP-8

3. Engine Durability Effects

The effects of JP-8 fueling on the durability of these engines are summarized in Fig. 31. Here, the engine deposits and measurements of critical components are presented as the percent change from base diesel fuel.

Starting at the left of Fig. 31, the combustion chamber deposits were measured following the GM 6.2L and Cummins NHC-250 tests. These measurements were made by scraping the deposits off and weighing them. In both cases, the amount of deposition was half of that compared to the DF-2 Cat fuel. JP-8 would be expected to result in less deposits due to the lower boiling point range.

The piston weighted total demerits (WTD) method is a Coordinated Research Council (CRC) technique for quantifying the varnish and carbon deposits on the pistons in the ring groove and land areas. Deposits in these areas can result both from the fuel and the lubricant.



*LARGE DIFFERENCE DUE TO ROD BEARINGS – IF ONLY MAINS ARE CONSIDERED, THEN NO DIFFERENCE
**NA - DATA NOT AVAILABLE

Figure 31. Engine durability, JP-8 to base fuel comparisons

With the exception of the LDT-465 engine, the JP-8 fueled engines produced more deposits. The faster combustion of the JP-8 may well lead to higher piston temperature and, therefore, greater deposits from the lubricant. The MAN combustion system of the LDT-465 may result in cooler pistons due to the faster evaporation of the JP-8 from the combustion zone of the piston. This effect is the opposite of that expected from the more conventional engines.

The amount of cylinder liner scuffing was not affected by the switch to JP-8 in three of the four engines tested. The 6V-53T engine showed an increase in scuffing. This high scuffing rating resulted from one particularly bad cylinder. Two of the six cylinders were reported as having no scuffing. It is, therefore, highly probable that the scuffing is the result of some nonuniformity in the pistons, rings or cylinder manufacture and fits, rather than a fuel effect.

Injector deposits were measured by air flow measurements through an open injector in the case of the GM 6.2L engine in accordance with an ISO standard procedure. The Cummins NHC-250 nozzles were rated for their flow characteristics by personnel at Ft.

Bliss, TX using the calibration procedures specified in the technical manual. Nozzle measurements were not made in the case of the GMC 6V-53T or LDT-465 engines.

As shown in Fig. 31, no change was detected in the nozzle deposits for the 6.2L engine. Some reduction was noted for the NHC-250 nozzles. JP-8 would be expected to produce fewer deposits (consisting primarily of varnish) due to its lower boiling point distribution. Jet turbine fuels are rated for their thermal stability, or resistance to forming such deposits, by the JFTOT, ASTM D 3241 tests. No such rating is required of diesel fuels.

Top ring end gap increase, or wear, was half that observed in the diesel fuel case for all the engines except the GM 6.2L engine. The significantly reduced wear of the top rings of the three engines would be due to less wetting of the cylinder walls by the JP-8 fuel. JP-8 will evaporate faster during the spray, resulting in less wall wetting. The cleaner burning of the JP-8 will also result in fewer solids passing the rings in the engine blowby.

It is not clear why significantly higher wear of the rings was observed for the JP-8 fuel. The GM 6.2L engine is the only prechamber design tested. As a prechamber design, it would not gain any advantage due to the faster evaporation of the JP-8. Only less wetting of the prechamber walls would result, which would not affect the top ring wear. Abnormal ring wear was not observed in the 400-hour NATO cycle test, suggesting that the test load factor is playing a role in the wear.

The rod and main bearing shells were weighed before and after the endurance test. The JP-8 fueling resulted in less weight loss for all the bearings except the NHC-250 rod bearing shells. In Fig. 31, the weight loss of both the rod bearings and mains are shown as well as just the main bearings for the NHC-250 engine.

Finally, no significant difference in scuffing was seen between the DF-2 and JP-8 injector needles. A tendency for higher scuffing would be expected due to the lower viscosity of the JP-8, especially at the elevated temperatures of the injectors.

4. Used Oil Analysis

Comparisons between the Cat fuel and JP-8 tests used oil are given in Fig. 32. In general, the lubricant analysis indicated less wear metals and improved lubricant performance for the JP-8.

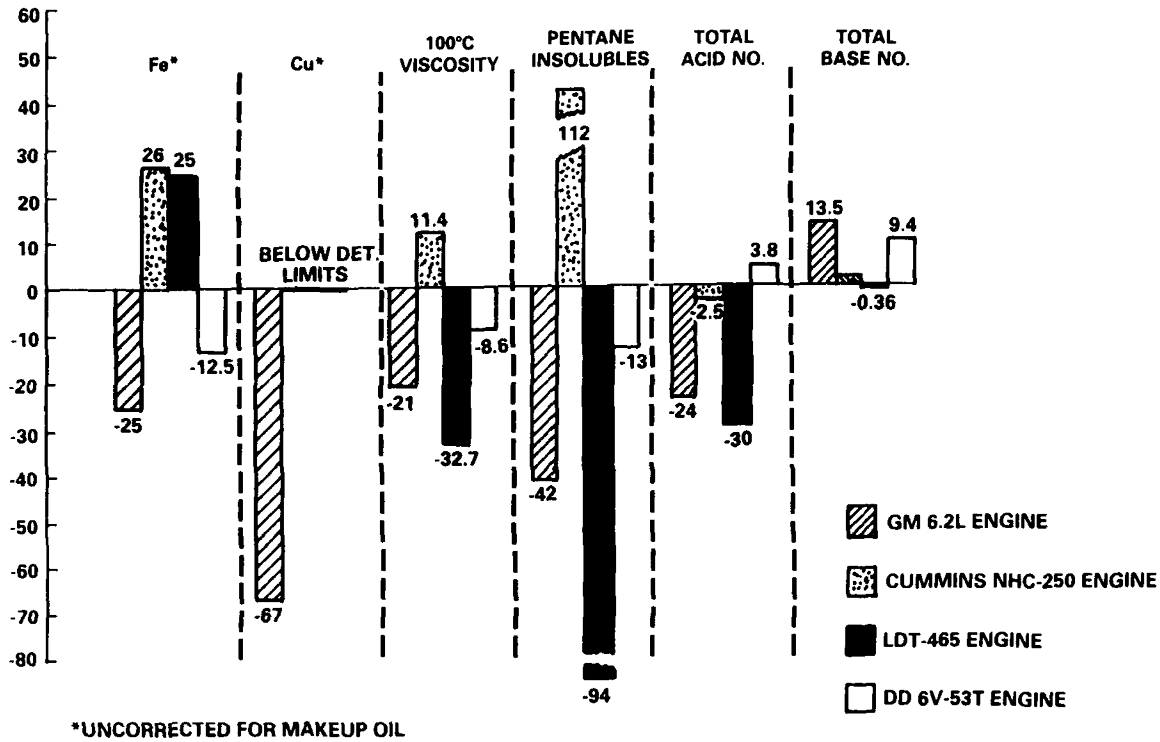


Figure 32. Used oil analysis, JP-8 to base fuel comparisons

Higher iron levels were found in the oil of the Cummins NHC-250 and LDT-465 engines. The total base numbers of these two engine lubricants were also close to the base fuel figures. Recalling that these two engines also produced power close to the base fuel performance (the NHC-250) or exceeding the base fuel (LDT-465), the higher loading of the lubricant due to increased blowby and greater wear metal makes sense. The decreased power output of the other two engines compared to the base fuel may well explain the apparently improved oil performance of the other engines.

The equal or lower level of the copper found in the lubricants is indicative of the lower acid number and corresponding higher base numbers.

V. CONCLUSIONS

The conclusions that can be drawn from the collection of these tests indicate that there are some advantages to using JP-8 in these engines. Some problems were also identified, which must be addressed.

Advantages of JP-8 that have been identified:

- JP-8 fueled engines place less stress on the lubricant in terms of acid levels and contaminants.

- Significantly less wear of the critical top ring was observed, which can prolong the serviceable life of the engine.

- Less combustion chamber deposits are formed, prolonging engine life.

- No change to a slight reduction occurred in injector scuffing and deposits.

- Thermal efficiency increased at maximum power condition of three of the four engines tested. The increased thermal efficiency offsets the inherent disadvantage of JP-8, namely, lower volumetric energy content. The net effect was sufficient to result in improved projected range for vehicles powered by the NHC-250 and the LDT-465.

The disadvantages that have been observed are:

- Slightly lower maximum power was available in engines not equipped with fuel density compensation.

- Higher volumetric fuel consumption resulted at part-load conditions in the DD 6V-53N engine. The percent difference in net energy content between DF-2 and JP-8 appears to be a conservative estimate of the increase in fuel consumption or decrease in range with this engine. Logistically, this higher consumption would require a greater quantity of JP-8 be purchased as compared to DF-2. Similar fuel consumption comparisons were not made for the other engines discussed in this report.

- Severe wear problems occurred in the standard rotary fuel injection pump used on the GM 6.2L engine. Further studies of this problem are reported in References 18 and 19. It was shown that the manufacturer's "arctic" pump configuration reduced the wear observed in laboratory testing.(18) A 10,000-mile vehicle testing program in desert conditions failed to produce any such wear (19), which indicates that the laboratory testing reported here may not correlate with field operations for these components.

VI. RECOMMENDATIONS

No significant problems were identified using JP-8 in any engine other than the GM 6.2L, which was later shown not to occur in field-tested vehicles. However, fuel temperatures were in the 90° to 100°F range (32° to 38°C). Therefore, it is recommended that a study be conducted to determine the maximum fuel temperatures at which the fuel injection equipment may be exposed. Then pump stand tests should be conducted to determine the durability of the injection equipment at the elevated fuel temperatures.

VII. REFERENCES

1. Bowden, J.N. and Owens, E.C., "Use of JP-5 in Diesel Engines," Letter Report AFLRL No. 182, Contract DAAK70-82-C-0001, Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, August 1984.

2. Bowden, J.N. and Owens, E.C. "JP-8 and JP-5 as Compression Ignition Engine Fuel," Interim Report AFLRL No. 192, AD A150796, Contract DAAK70-85-C-0007, Belvoir Fuels and Lubricants Research Facility at Southwest Research Institute, San Antonio, TX, January 1985.

3. Lestz, S.J. and Bowen, T.C., "Development of Army Synthetic Automotive Engine Oils for Arctic Service," Interim Report AFLRL No. 73, AD A019113, Contract Nos. DAAD05-70-C-250 and DAAK02-73-C-0221, Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, September 1975.

4. Stavinoha, L.L., Eichelberger, J.R., Lestz, S.J., and Tyler, J.C. "Lubricant Volatility Related to Two-Cycle Diesel-Engine Piston-Ring/Cylinder-Liner Wear," Presented at ASLE/ASME Lubrication Conference, San Francisco, CA, August 1980, preprint No. 80-LC-3C; also, J. ASLE, Vol. 38, 1, pp. 11-22, January 1982.

5. Lestz, S.J. and Bowen, T.C., "Army Experience With Synthetic Engine Oils in Mixed Fleet Arctic Service," Society of Automotive Engineers Paper No. 750685, presented at SAE Fuels and Lubricants Meeting, Houston, TX, June 1975.

6. Lestz, S.J., Bowen, T.C. and LePera, M.E., "Fuel and Lubricant Compatibility Studies for Army High-Output Two-Cycle Diesel Engines," Interim Report AFLRL No. 80, AD A031885, Contract Nos. DAAD05-70-C-0250, DAAK02-73-C-0002, DAAG53-76-C-0003, Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, September 1986.

7. Lestz, S.J., LePera, M.E. and Bowen, T.C., "Fuel and Lubricant Effects on Army Two-Cycle Diesel Engine Performance," Society of Automotive Engineers Paper No. 760717, presented at Automobile Engineering Meeting, Dearborn, MI, October 1976.

8. Owens, E.C., Lestz, S.J. and Quillian, Jr., R.D., "Appraisal of Extended Oil Drain Intervals Through the Use of Engine or Lubricant Formulation Modification," Interim Report AFLRL No. 99, AD A055923, Contract No. DAAK70-78-C-0001, Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, May 1978.

9. Owens, E.C., Lestz, S.J. and Quillian, Jr., R.D., and McCormick, H.E., "Approaches to Extended Oil Drain Intervals in Army Tactical Equipment," Society of Automotive Engineers Paper No. 780954, presented at SAE International Fuels and Lubricants Meeting, Toronto, Canada, November 1978.

10. Moon, R.B. and Montemayor, A.F., "Laboratory Evaluation of Multiviscosity Grade Engine Oils in U.S. Army Diesel Engines," Interim Report AFLRL No. 112, AD A108890, Contract No. DAAK70-80-C-0001, Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, September 1981.

11. Montemayor, A.F., Owens, E.C., Frame, E.A., Lestz, S.J. and Bowen, T.C., "Laboratory Evaluation of Army Multiviscosity Grade Tactical Engine Oils," Society of Automotive Engineers Paper No. 831719, Presented at SAE Fuels and Lubricants Meeting, San Francisco, CA, November 1983.

12. Lestz, S.J., Wright, B.R. and Bowen, T.C., "50,000-Mile Engine-Lubricant Field Test of XM809 Series 5-Ton Vehicles," Final Report AFLRL No. 11, AD 734349,

Contract No. DAAD05-70-C-0250, Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, August 1971.

13. "Development of Military Fuel/Lubricant/Engine Compatibility Test," Final Report, Coordinating Research Council, Inc., New York, NY, January 1967.

14. Federal Test Method Standard 791C "Lubricants, Liquid Fuels, and Related Products; Methods of Testing," 30 September 1986.

15. Federal Specification VV-F-800D, "Fuel Oil, Diesel," 27 October 1987.

16. U.S. Military Specification MIL-T-83133B, Turbine Fuel, Aviation, Kerosine Type, Grade JP-8, 3 September 1987.

17. U.S. Military Specification MIL-L-2104D, "Lubricating Oil, Internal Combustion Engine, Tactical Service," April 1983.

18. Montemayor, A.F. and Owens, E.C., "Comparisons of 6.2L Arctic and Standard Fuel Injection Pumps Using JP-8 Fuel," Interim Report BFLRF No. 218, AD A175597, Contract DAAK70-85-C-0007, Belvoir Fuels and Lubricants Research Facility at Southwest Research Institute, San Antonio, TX, October 1986.

19. Goss, D.E., "10,000-Mile JP-8 Fuel Test--6.2L Diesel Engine in M1028 CUCV Vehicles," Final Report, Prepared by General Motors Technical Center, Warren, MI, January 1986.

APPENDIX A

Test Data and Photographs

GM 6.2L Engine

210-Hour Test

Cat Fuel*

Initial Baseline

*Use of designation "Cat 1-H" test fuel refers to Reference No. 2 Diesel Fuel, or simply Cat Fuel.

GM 6.2L
CAT 1-H
LOG OF UNSCHEDULED EVENTS

Test Time Hours	EVENT
28	Oil Cooler Cleaned
57	Leaking Oil; Cooler Line Replaced
70	Oil Changed
85	Oil Cooler Line Fitting Tightened
126	Oil Changed; Exhaust Routed Away From Oil Pan
141	New Air Cleaner Fitted
182	Oil Changed
190	Maximum Power Condition Set According To Fuel Flow Rate of 67-68 lb/hr

GM 6.2 l
CAT 1 H
ENGINE MEASUREMENTS
SERIAL NUMBER: DJ-921

	Minimum	Maximum	Average	Specified Limits
Cylinder Bore				
Diameter	3.9775	3.9787	3.9779	3.9759 - 3.9789
Out of Round	0.0000	0.0008	0.0002	—— 0.0008
Taper-Thrust	0.0000	0.0004	0.0002	—— 0.0008
Piston Clearances				
Bores 1-6	0.0043	0.0048	0.0045	0.0035 - 0.0045
Bores 7-8	0.0051	0.0052	0.0052	0.0040 - 0.0050
Piston Rings				
Groove Clearance				
2nd	0.002	0.002	0.002	0.0015 - 0.0030
Oil	0.002	0.002	0.002	0.0016 - 0.0038
End Gap				
Top	0.026	0.027	0.026	0.012 - 0.022
2nd	0.041	0.042	0.042	0.029 - 0.039
Oil	0.025	0.028	0.026	0.010 - 0.020
Piston Pin				
Diameter	1.2203	1.2208	1.2206	1.2203 - 1.2206
Clearance	0.0004	0.0006	0.0005	0.0004 - 0.0006
Fit in Rod	0.0003	0.0008	0.0006	0.0003 - 0.0012
Camshaft				
Diameters				
Bearings 1-4	2.1659	2.1660	2.1659	2.1644 - 2.1663
Bearing 5	N/A	N/A	2.0085	2.0069 - 2.0088
Clearance	0.0019	0.0023	0.0021	0.0015 - 0.0044
Crankshaft				
Journal				
Diameter 1-4	2.9499	2.9500	2.9500	2.9495 - 2.9504
Diameter 5	N/A	N/A	2.9499	2.9493 - 2.9502
Out of Round	0.0000	0.0002	0.0001	—— 0.0002
Clearance 1-4	0.0034	0.0038	0.0037	0.0018 - 0.0033
Clearance 5	N/A	N/A	0.0036	0.0022 - 0.0037
Crankpin				
Diameter	2.3985	2.3986	2.3986	2.3981 - 2.3992
Out of Round	0.0000	0.0005	0.0002	—— 0.0002
Clearance	0.0035	0.0047	0.0038	0.0018 - 0.0039
Valve				
Stem Clearance				
Intake	0.0019	0.0022	0.0022	0.001 - 0.0027
Exhaust	0.0023	0.0030	0.0028	0.001 - 0.0027

NOTE: Measurements are in inches.

ANALYSIS OF CAT 1-H FUEL, BATCH 85-2 (AL-14069-F)

Test	AFLRL Data	Howell Data	Howell Cat 1-H Limit
Gravity, °API	34.5	34.5	32.0-35.0
Specific Gravity, 15.6/15.6°C	0.8524		
Distillation, °F(°C)			
IBP	402(206)	384(196)	Report
10% recovered	462(239)	467(242)	Report
50% recovered	517(269)	518(270)	500-530
90% recovered	611(322)	612(322)	580-620
EP	663(351)	664(351)	650-690
% recovered	99	—	(a)
% residue	1	—	(a)
Flash Point, °F(°C)	180(82)	180(82)	Report
Pour Point, °F(°C)	9(-13)	+5(-15)	+20 max
Cloud Point, °F(°C)	14(-10)	14(-10)	Report
Copper Corrosion, 3 hr at 210°F, Rating	1A	1A	2 max
Carbon Residue on 10% Bottoms, Ramsbottom wt%	0.11	0.13	0.20 max
Water and Sediment, vol%	<0.01	0.05	0.05 max
Neutralization Number, mg KOH/g	0.02	0.02	0.15 max
Ash, wt%	<0.01	0.006	0.01 max
Viscosity at 100°F (37.8°C), cSt	(b)	3.18	3.0-4.0
Viscosity at 40°C, cSt	2.98	(b)	(a)
Net Heat of Combustion, Btu/lb	18,279	(b)	(a)
MJ/kg	42,516	(b)	(a)
Cetane Number	52	51	45-51
Cetane Index	47	47	(a)
Carbon, wt%	86.24	—	(a)
Hydrogen, wt%	12.19	—	(a)
Sulfur, wt%	0.41	0.40	0.37-0.43

(a) - No requirement

(b) - Not determined

GM 6.2 l ENGINE
OPERATING CONDITIONS SUMMARY
LUBRICANT: AL-14080-L
CAT-1H FUEL: 14069-F

	Full Power Mode (3600 RPM)		Idle Mode (800 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed (rpm)	3600	0.504	801	4.00
Torque (ft-lb)	210	9.32	9.53	2.21
Fuel Consumption (lb/hr)	76.0	2.86	4.36	0.340
Observed Power (Bhp)	144	6.39	1.48	0.343
BSFC (lb/Bhp-hr)	0.527	0.0812	5.32	17.9
Oil Gallery Pressure (psi)	52.7	2.35	53.4	2.16
Temperatures (^{o}F)				
Water Jacket Inlet	162	1.37	93.3	13.2
Water Jacket Outlet	178	1.74	101.0	12.8
Oil Sump	239	1.74	124.2	3.10
Fuel Inlet	101	3.03	86.5	3.56
Air Inlet	91.4	5.48	85.1	4.05
Exhaust Temperatures (^{o}F)				
Cylinder 1	1268	36.6	153.5	9.71
Cylinder 2	1251	34.2	144.6	8.89
Cylinder 3	1287	36.0	142.1	8.99
Cylinder 4	1241	40.9	160.0	6.31
Cylinder 5	1413	28.0	193.1	14.99
Cylinder 6	1274	39.8	159.5	5.87
Cylinder 7	1307	38.9	178.0	9.35
Cylinder 8	1289	45.2	180.7	10.56
Common	1191	108.9	141.3	10.49

GM 6.2L
CAT 1-H
WEAR METALS BY XRF
LUBRICANT: AL-14080-L

Test Time Hours	Wear Metals ppm Fe	Cu	Cr	Pb	S%
0	10	11	10	60	0.43
14	65	11	10	60	0.48
28	122	24	10	60	0.49
42	210	22	10	60	0.50
56	286	22	10	85	0.49
70	360	25	10	152	0.50
84	175	13	10	65	0.48
98	205	13	10		0.49
112	250	12	10	82	0.50
126	330	12	10	149	0.53
140	140	11	10	60	0.48
154	193	10	10	92	0.51
168	205	10	10	78	0.51
182	230	11	10	60	0.55
196	100	10	10	60	0.51
210	132	11	10	60	0.51

GM 6.2L
CAT 1-H
LUBRICANT: AL-14080

	ASTM Method	Test Time, Hours 0	70	140	210
Kinematic Viscosity @ 40°C cSt	D 445	97.13	402.20	--	172.48
Kinematic Viscosity @ 100°C cSt	D 445	11.04	64.83	25.52	22.59
Total Acid Number mg KOH/g	D 664	2.51	9.56	--	5.85
Total Base Number mg KOH/g	D 664	6.49	0.50	--	1.87
Pentane B Insolubles wt%	D 893	--	9.31	--	4.24
Toluene B Insolubles wt%	D 893	--	9.01	--	3.36
Flash Point, °C	D 92	230	232	--	230

GM 6.2 l
CAT 1 H
WEAR MEASUREMENTS

Cylinder Bore Diameter Change

	1 T-AT	1 F-B	3 T-AT	3 F-B	5 T-AT	5 F-B	7 T-AT	7 F-B
Top	0.0007	0.0005	0.0003	0.0010	0.0007	0.0005	0.0006	0.0007
Middle	0.0010	0.0004	0.0005	0.0005	0.0007	0.0004	0.0006	0.0004
Bottom	0.0005	0.0007	0.0004	0.0010	0.0005	0.0008	0.0004	0.0006

	2 T-AT	2 F-B	4 T-AT	4 F-B	6 T-AT	6 F-B	8 T-AT	8 F-B
Top	0.0005	0.0010	0.0005	0.0007	0.0005	0.0008	0.0000	0.0002
Middle	0.0005	0.0006	0.0003	0.0005	0.0004	0.0004	0.0002	0.0003
Bottom	0.0002	0.0010	0.0002	0.0009	0.0002	0.0012	0.0006	0.0004

Average Change

	T-AT	F-B
Top	0.0005	0.0007
Middle	0.0005	0.0004
Bottom	0.0004	0.0008

Overall Average Change: 0.0006

Piston Ring End Gap Change

Ring	1	2	3	4	5	6	7	8	Average Change
Top	0.002	0.002	0.002	0.004	0.006	0.004	0.004	0.005	.004
2nd	0.002	0.000	0.002	0.002	0.003	0.002	0.003	0.003	.002
Oil	0.000	0.008	0.005	0.004	0.005	0.006	0.005	0.004	.005

Overall Average: 0.004

Keystone Top Ring Proudness

0.0027	-0.0001	0.0046	0.0020	0.0025	0.0024	0.0032	0.0044	0.0027

Bearing Weight Change

Main Bearings									
Upper	-0.3734	-0.0080	3.6283	-0.1399	-0.0640				0.7612
Lower	-0.3178	-2.8641	1.3877	-0.1809	-0.9169				-0.2116
Rod Bearings									
Upper	0.1271	0.0545	0.1108	0.0653	0.0727	0.0852	0.0532	0.0257	0.0743
Lower	0.1115	0.1939	0.1813	0.3130	0.2168	0.1265	0.2638	0.0069	0.1767

Overall Average: 0.1255 grams

Valve Recession

Intake	0.0002	-0.0014	-0.0022	-0.0001	-0.0039	-0.0002	-0.0053	-0.0021	-0.0013
Exhaust	0.0016	-0.0021	-0.0005	-0.0017	-0.0024	-0.0012	-0.0036	-0.0023	-0.0015

Overall Average: -0.0014

NOTE: Measurements are in inches.

GM 6.2 1
CAT 1 H
POST TEST ENGINE CONDITION AND DEPOSITS

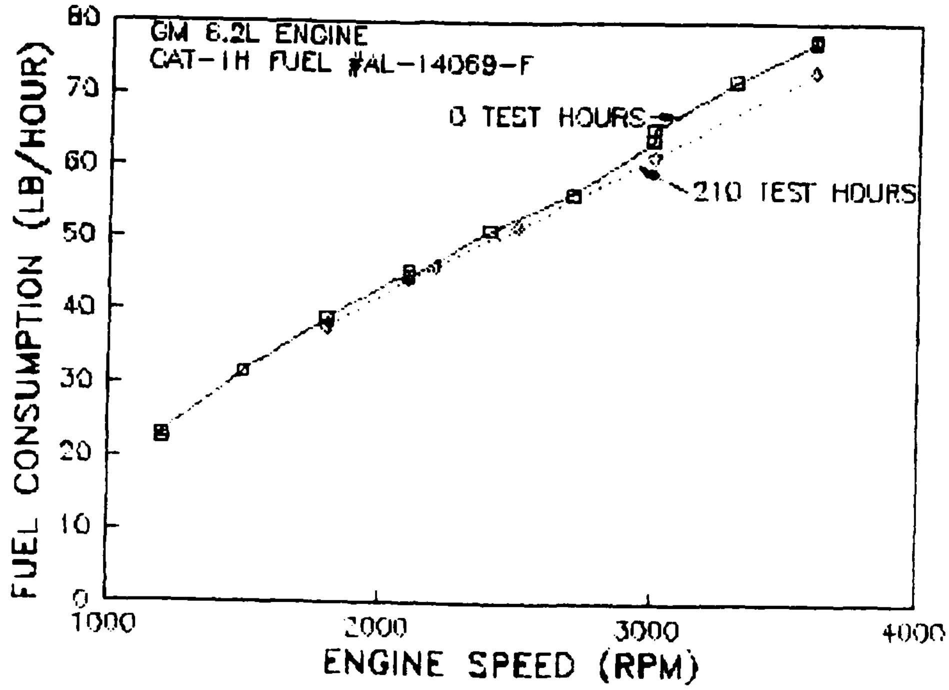
	Cylinder Number								
	1	2	3	4	5	6	7	8	AVG
Cylinder Liner									
Liner Scuffing, % Area									
Thrust	1	2	2	0	1	0	1	0	2.25
Anti-Thrust	0	0	0	2	0	2	0	1	0.63
% Total Area	0.5	1.0	1.0	1.0	0.5	1.0	0.5	0.5	0.75
								Overall:	0.75
Liner Polished, % Area									
Thrust	5	10	0	5	0	5	0	10	3.13
Anti-Thrust	0	0	0	0	0	0	0	0	0.00
% Total Area	2.5	5.0	0.0	2.5	0.0	2.5	0.0	5.0	1.94
								Overall:	1.94
Pistons									
Ring Face Distress Demerits									
Top	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0625
2nd	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1875
								Overall:	0.1250
Piston Skirt Rating									
Thrust	S*	S	N*	S	S	S	N	N	
Anti-Thrust	S	S	N	S	S	S	N	N	
Piston WTD Rating	122.50	101.00	102.25	143.25	141.13	145.25	125.25	155.38	131.02
Exhaust Valves									
Deposits									
Head	1/4 ASC**								
Face	Clean								
Tulip	0.5***	0.5	1.0	1.0	0.5	1.0	1.0	1.0	
Steam	Clean								
Surface Condition									
Freeness in Guide	Free								
Head	Normal								
Face	Light Pitting								
Seat	Light to Medium Wear								
Steam	Normal								
Tip	Normal								
Other Ratings									
Prechamber Deposits (grams)	0.11	0.07	0.11	0.05	0.06	0.08	0.03	0.06	0.07
Bearing Surface	#3 Main Scratched								

* S - scratched, N - normal
** 1/4 ASC; soft carbon, prefix indicates carbon depth with 1/4 ASC being the least to J the most.
*** The Higher the number the darker the lacquer, 0-9.

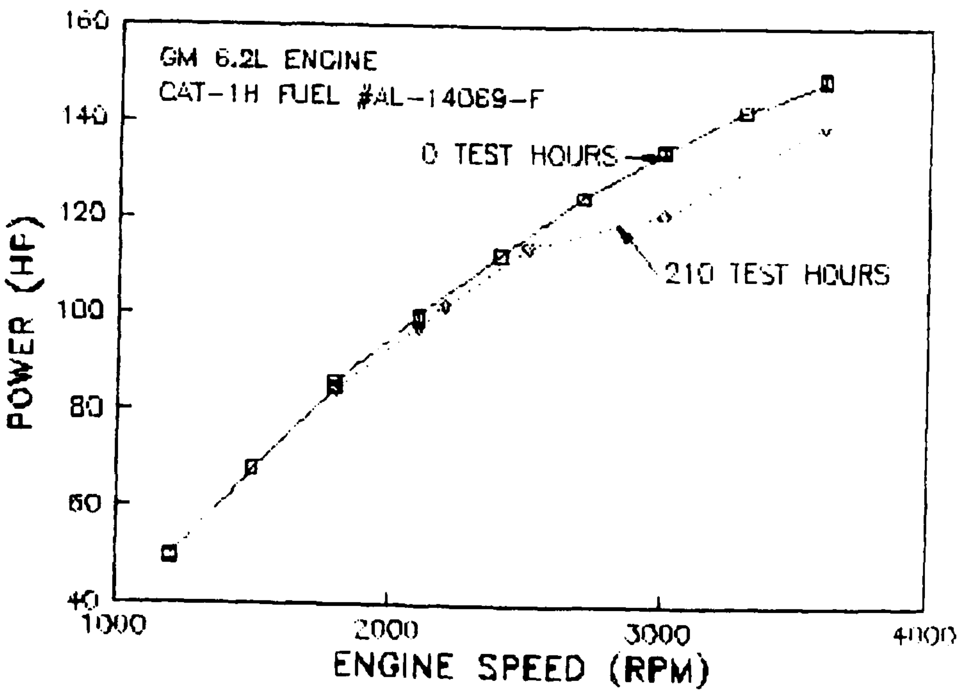
GM 6.2 1
CAT 1 H
FUEL INJECTOR AND PUMP TESTS
ENGINE SERIAL NUMBER: DJ-921

	Cylinder Number								
	1	2	3	4	5	6	7	8	AVG
Pop-Off Pressure (psi)									
Before Test	2200	1700	1800	1750	1500	2250	2200	2100	1938
After Test	1600	1600	1750	1650	1350	1750	1700	1850	1656
	Overall Decrease: 282 psi								
Report									
Before Test	Yes								
After Test	No								
Fuel Pump Calibration									
(ml/min) @ 1000 RPM									
Before Test	46.0	47.5	47.0	48.0	48.0	45.5	46.0	46.0	46.8
After Test	46.0	47.0	46.0	48.0	48.0	45.5	45.5	46.0	46.5
	Overall Decrease: 0.2 ml/min								
(ml/min) @ 1800 RPM									
Before Test	—	—	—	—	—	—	—	—	—
After Test	90.9	94.5	92.4	99.5	89.5	91.4	85.8	90.4	91.8

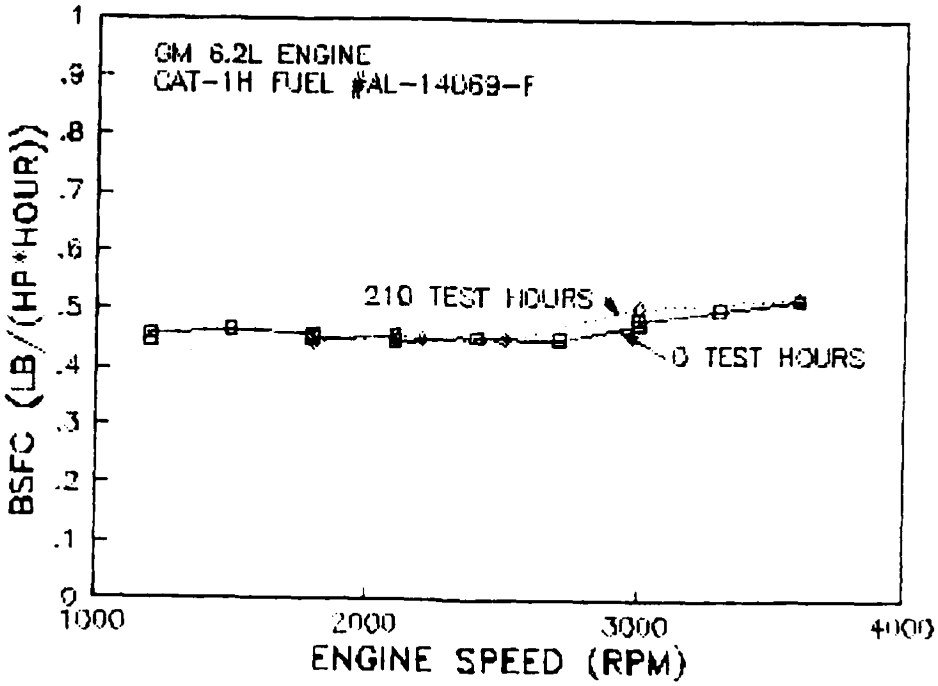
FULL LOAD FUEL CONSUMPTION



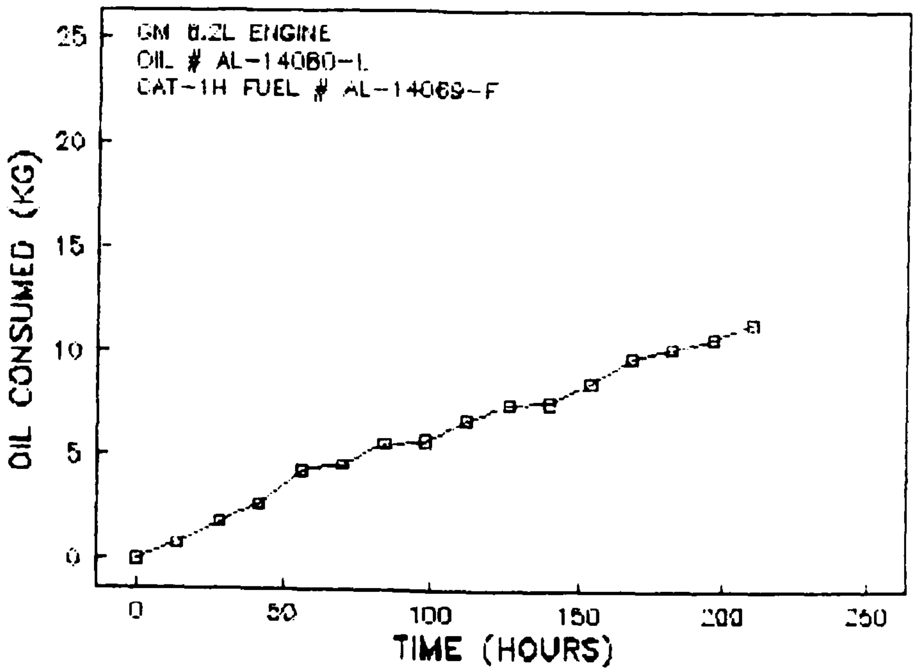
FULL LOAD POWER CURVES



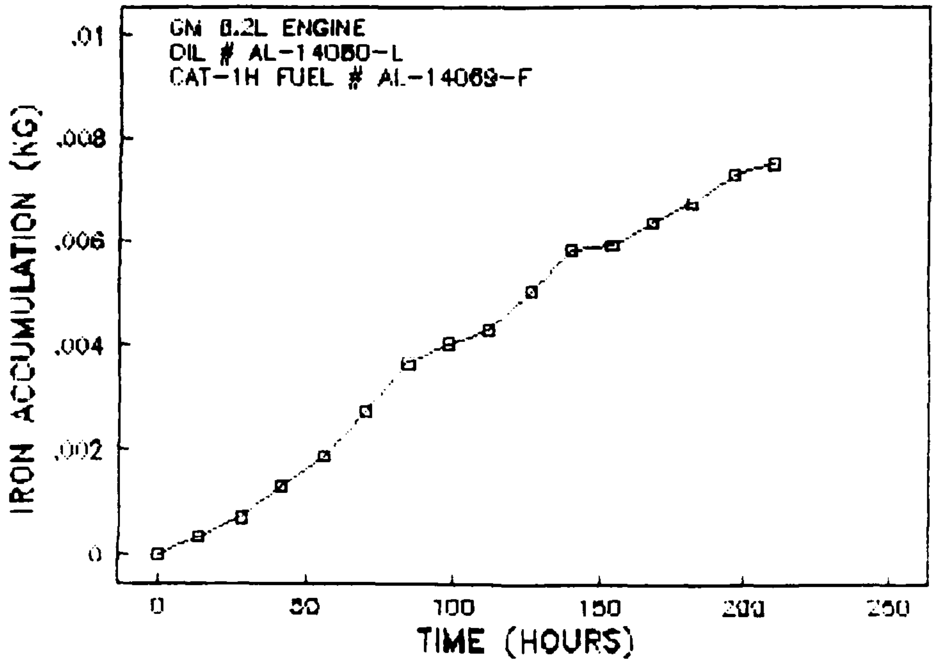
FULL LOAD BSFC CURVES



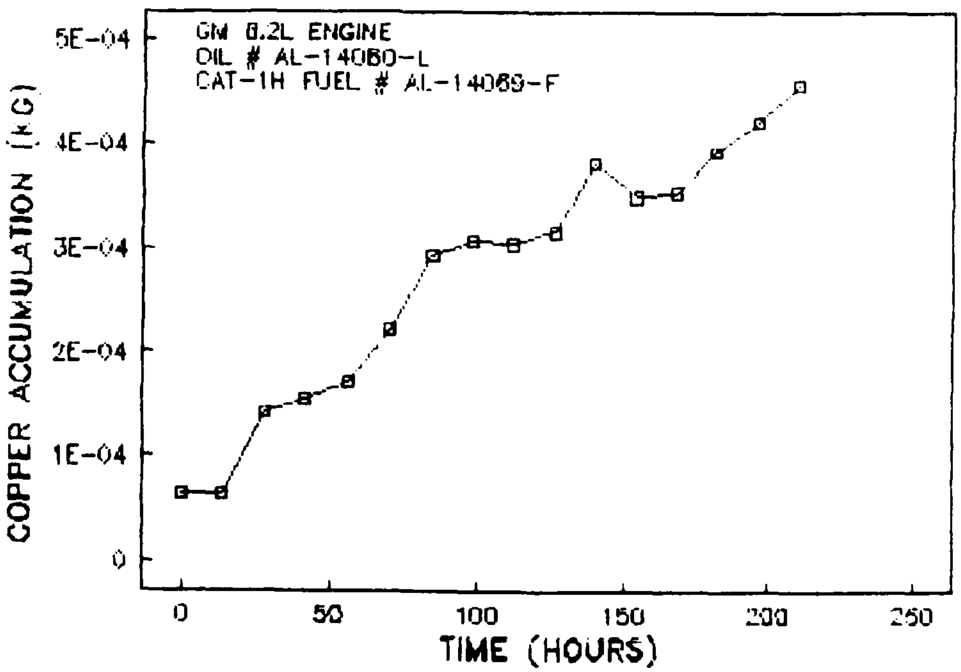
TOTAL OIL CONSUMPTION



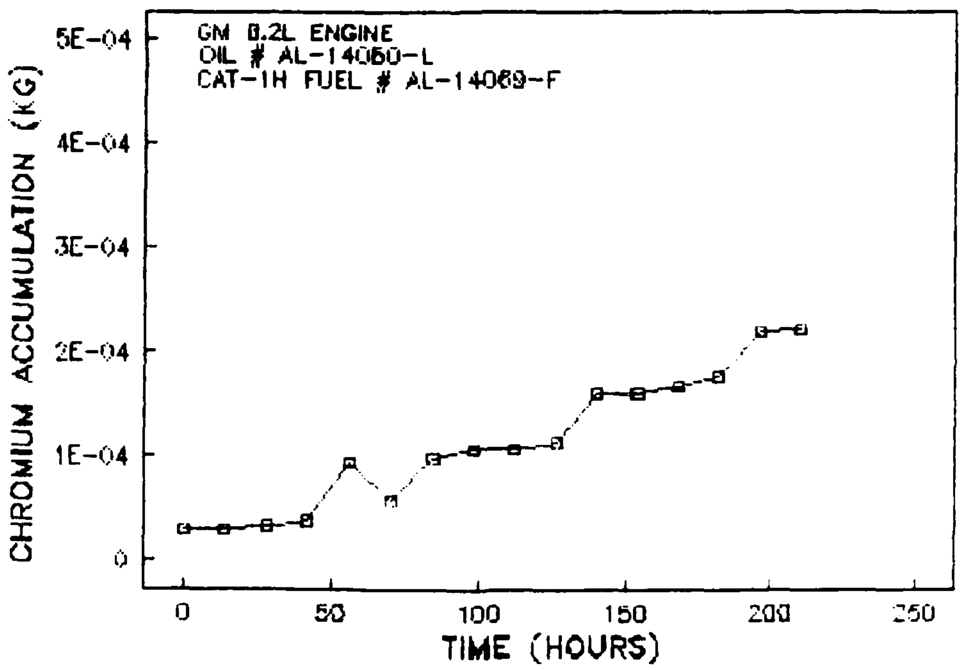
TOTAL IRON ACCUMULATION



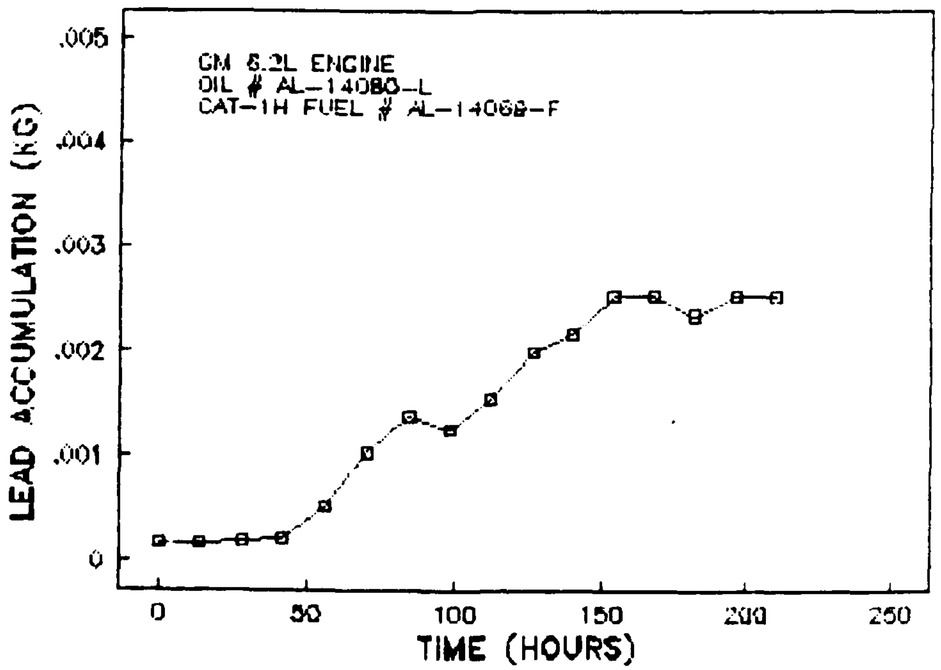
TOTAL COPPER ACCUMULATION



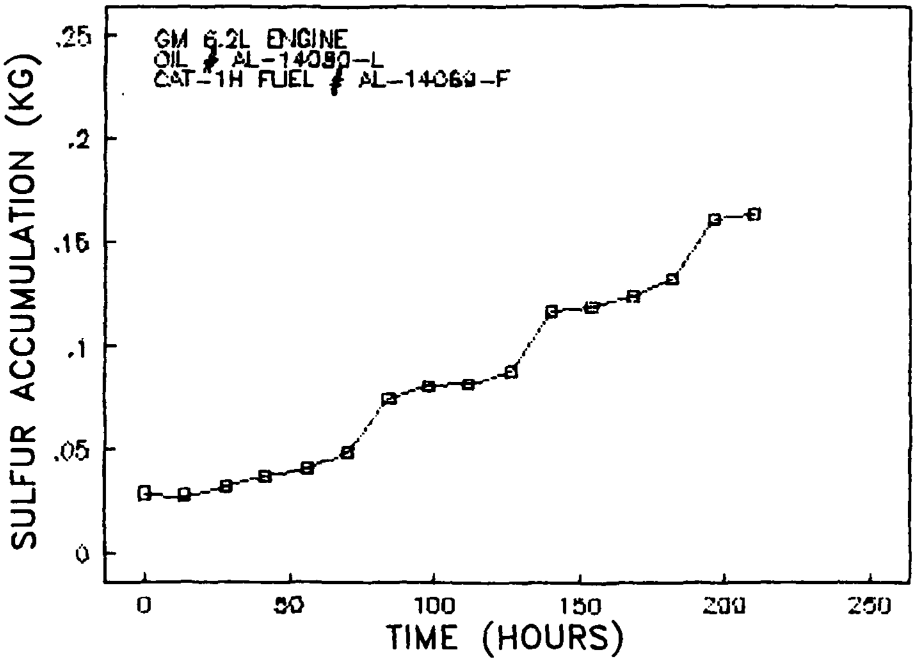
TOTAL CHROMIUM ACCUMULATION

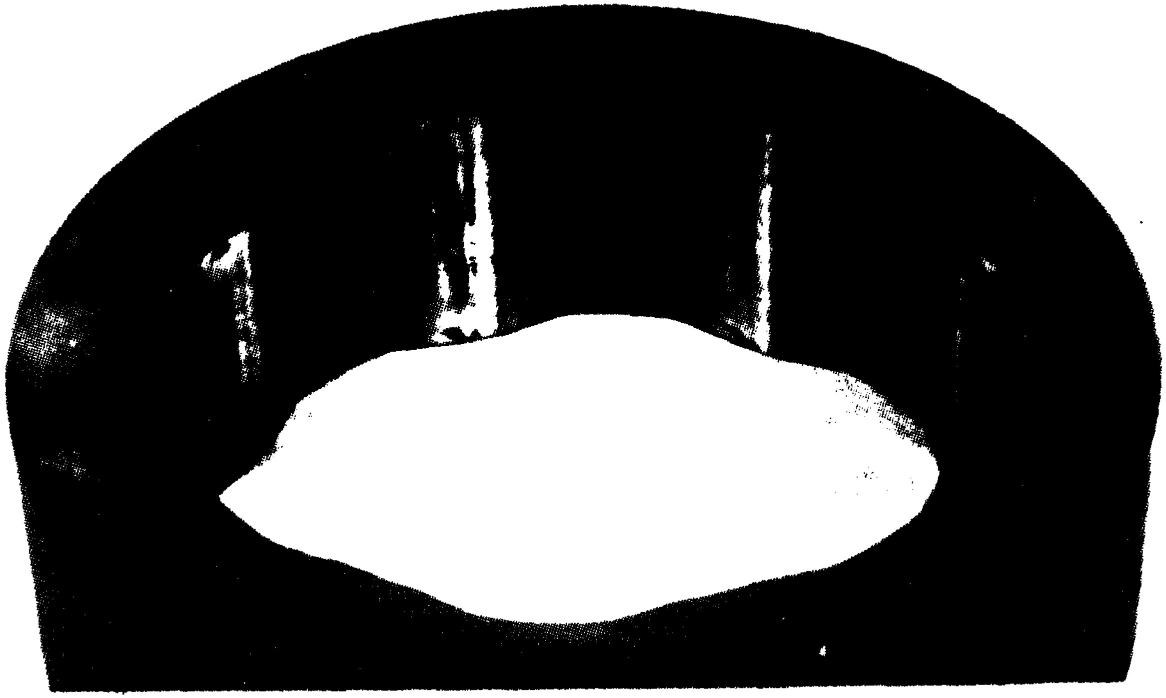


TOTAL LEAD ACCUMULATION



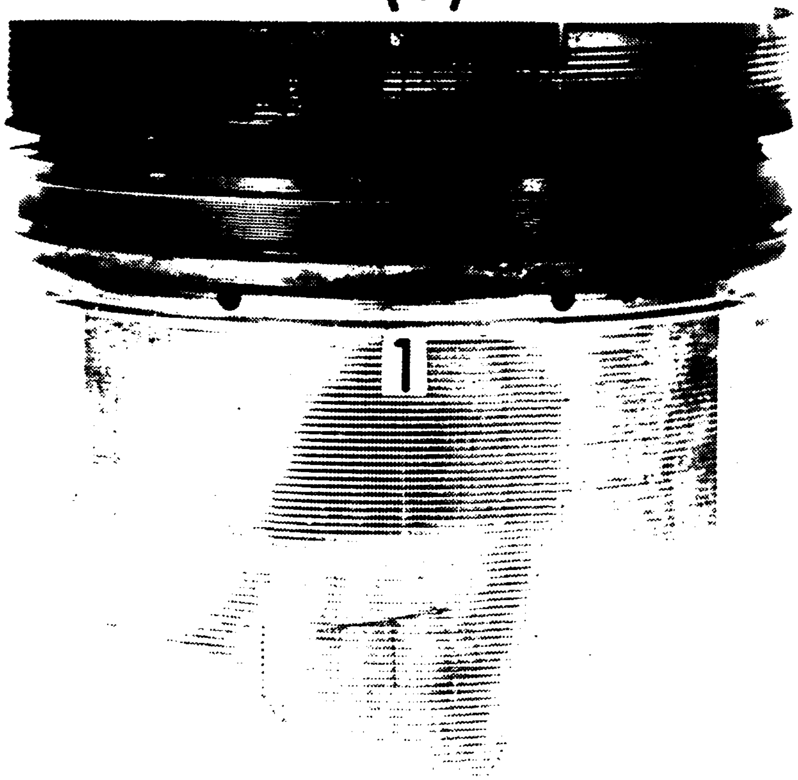
TOTAL SULFUR ACCUMULATION



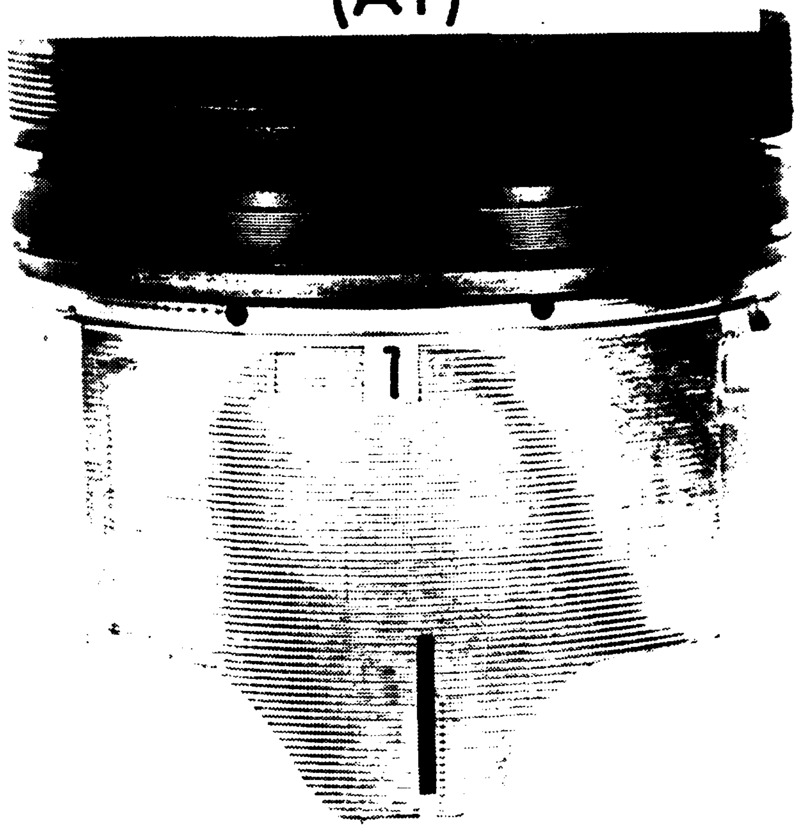


6.2 LITER G.M.
FUEL EVALUATION
TEST #1 FUEL PUMP

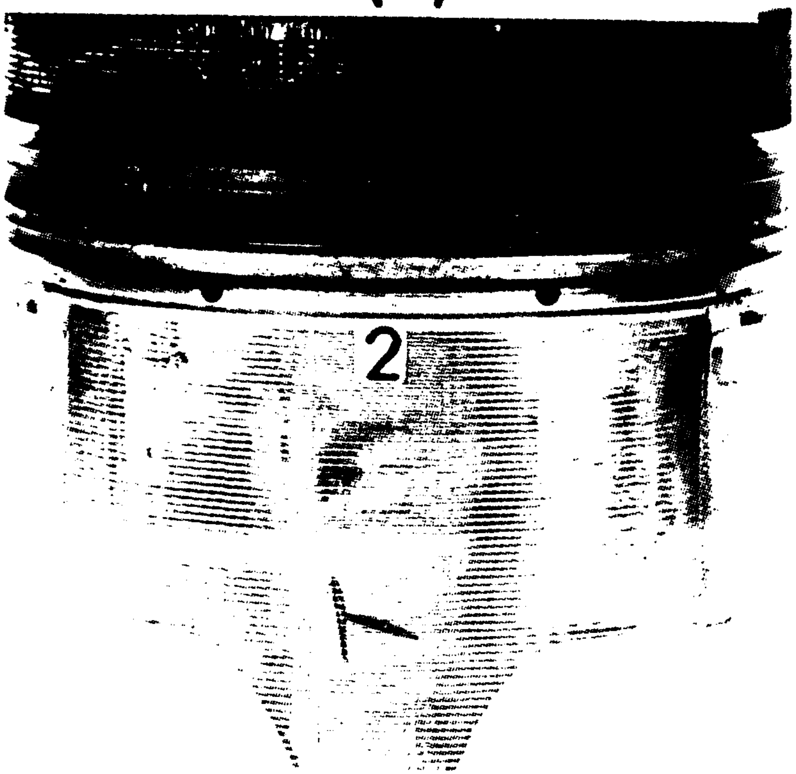
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(T)



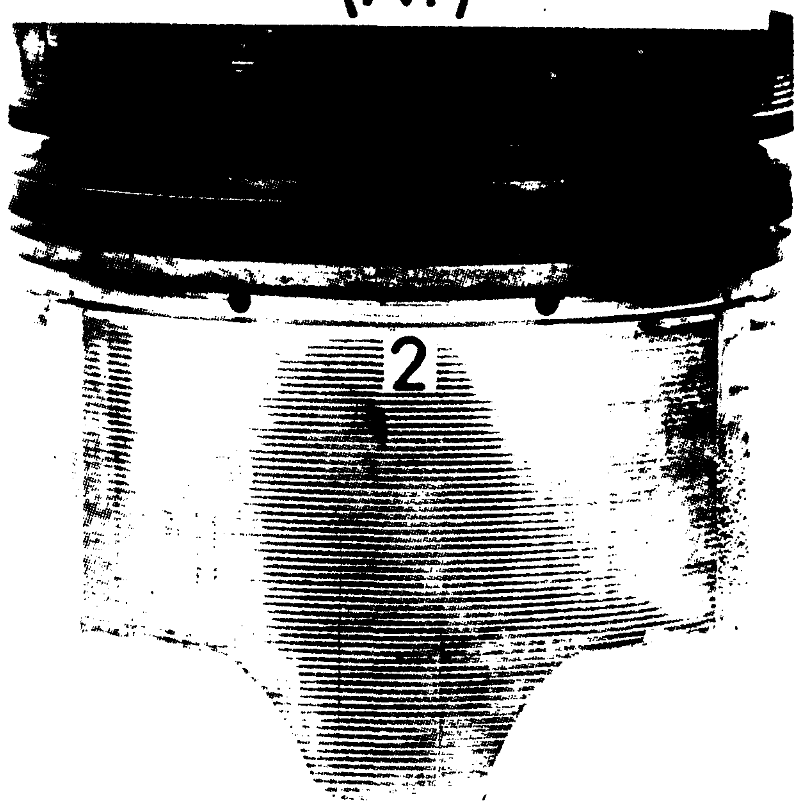
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(AT)



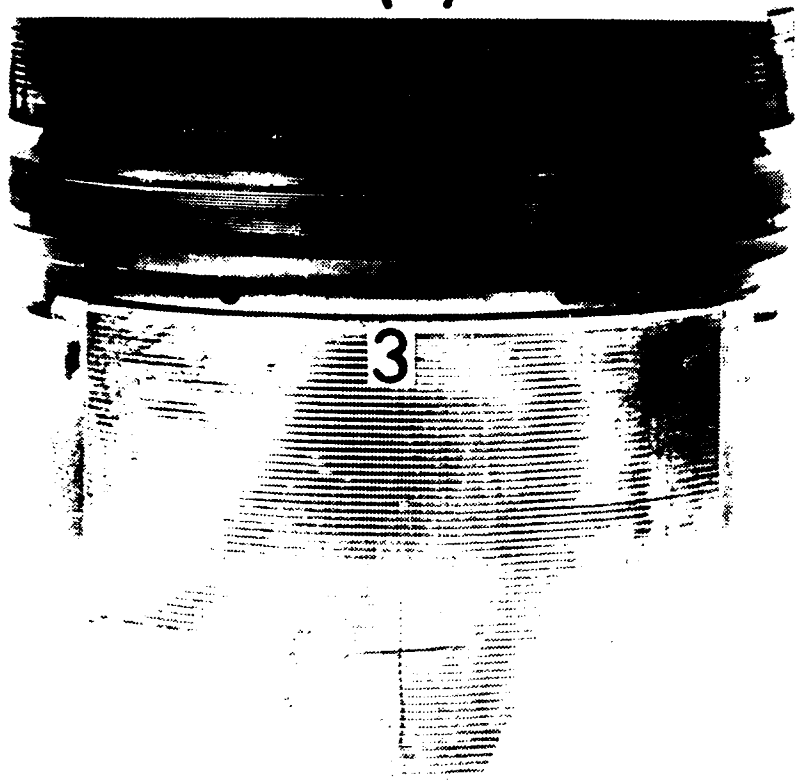
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(T)



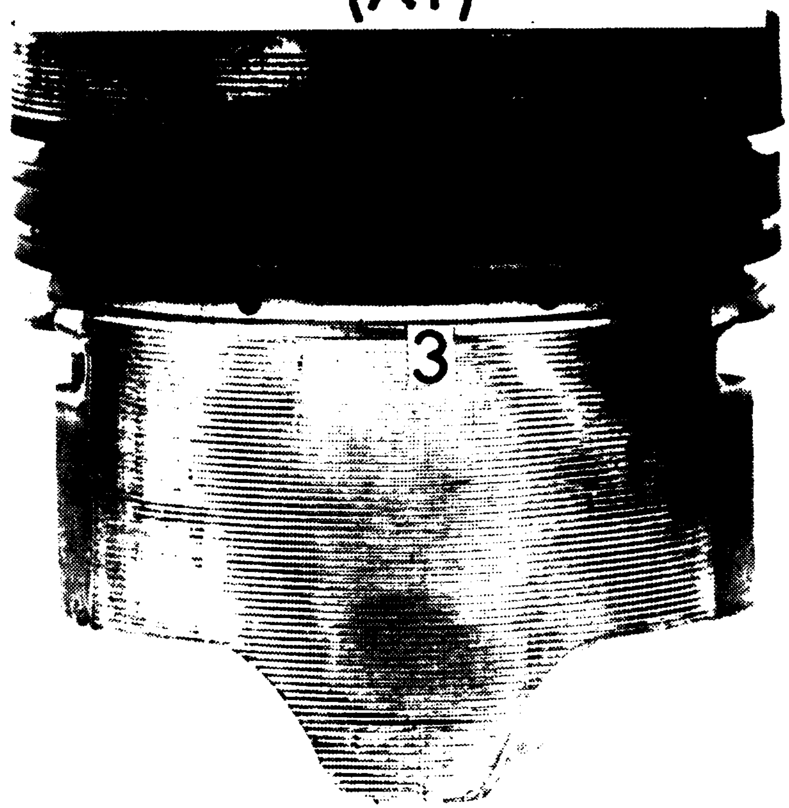
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(AT)



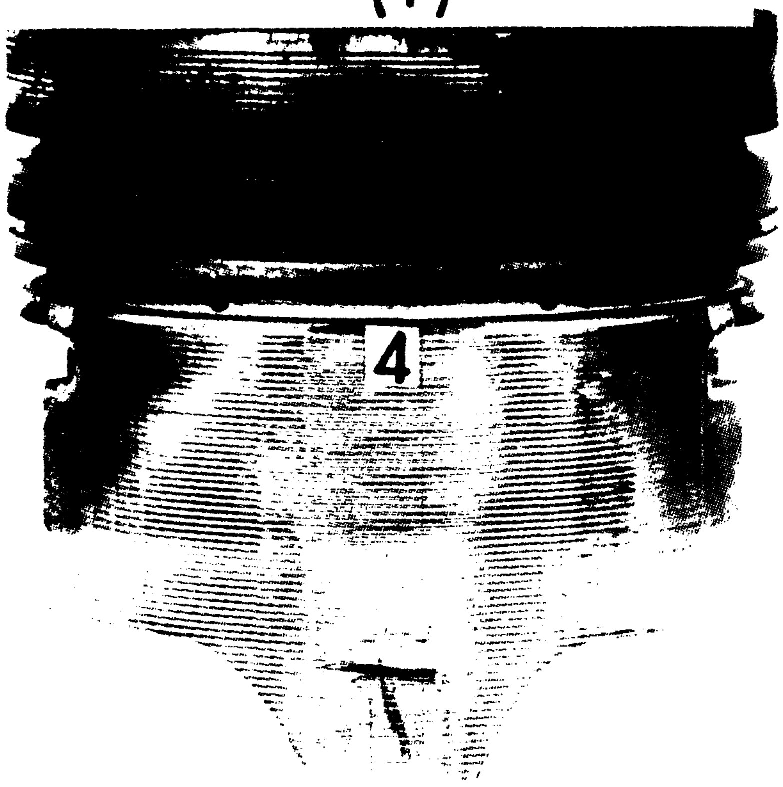
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(T)



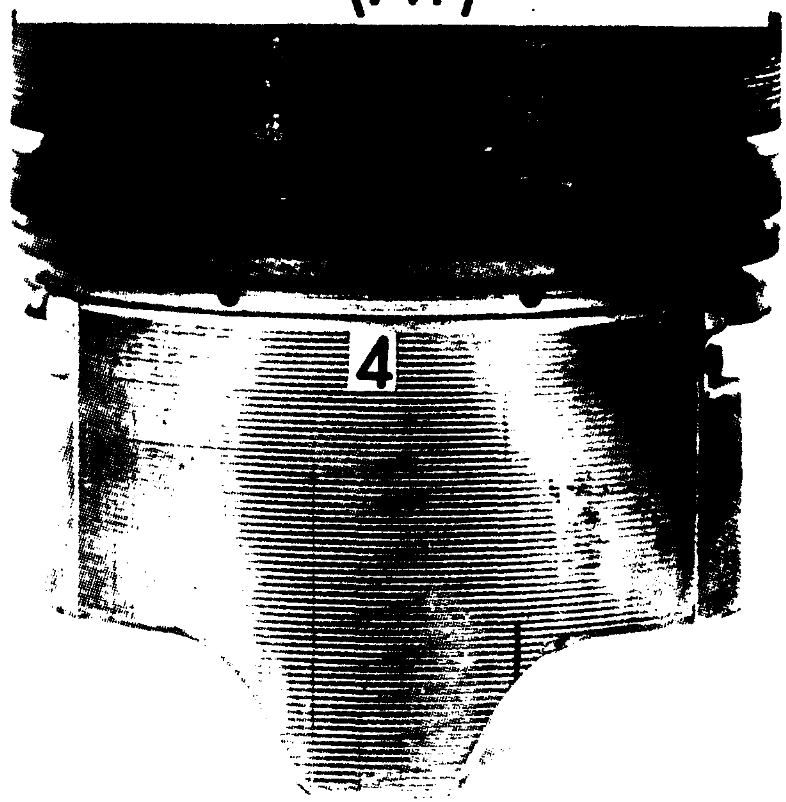
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(AT)



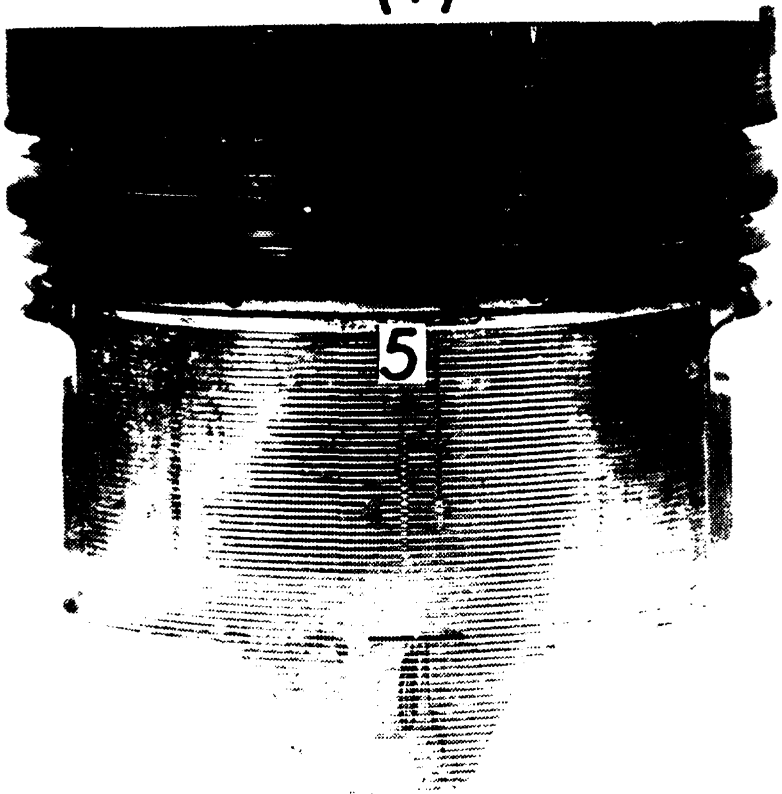
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(T)



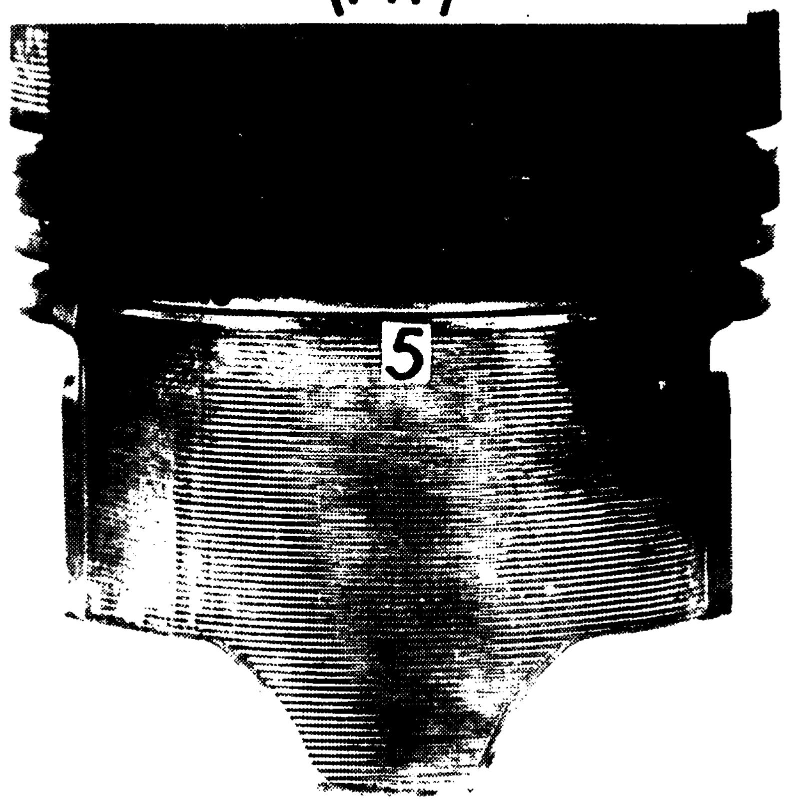
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(AT)



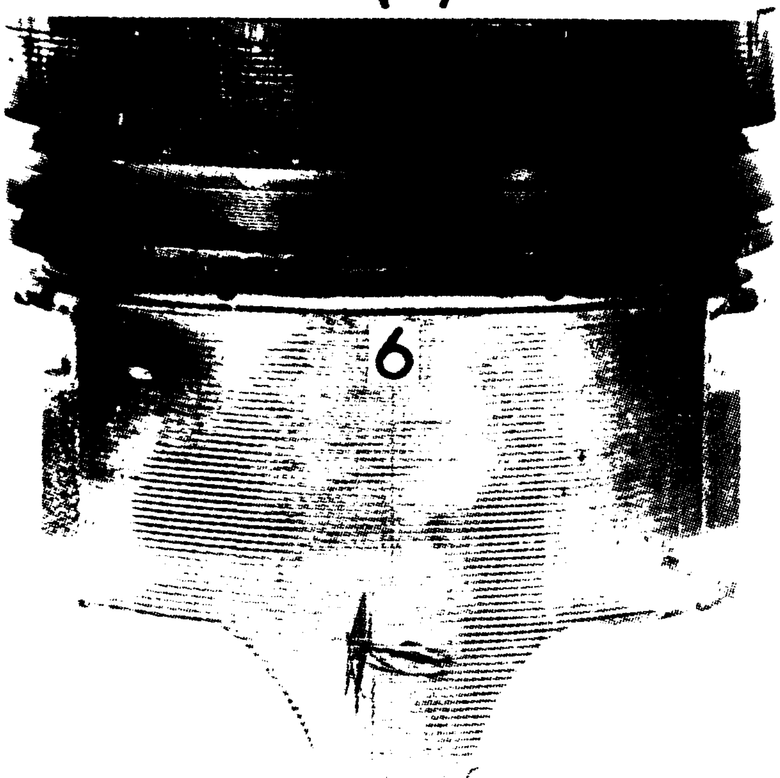
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(T)



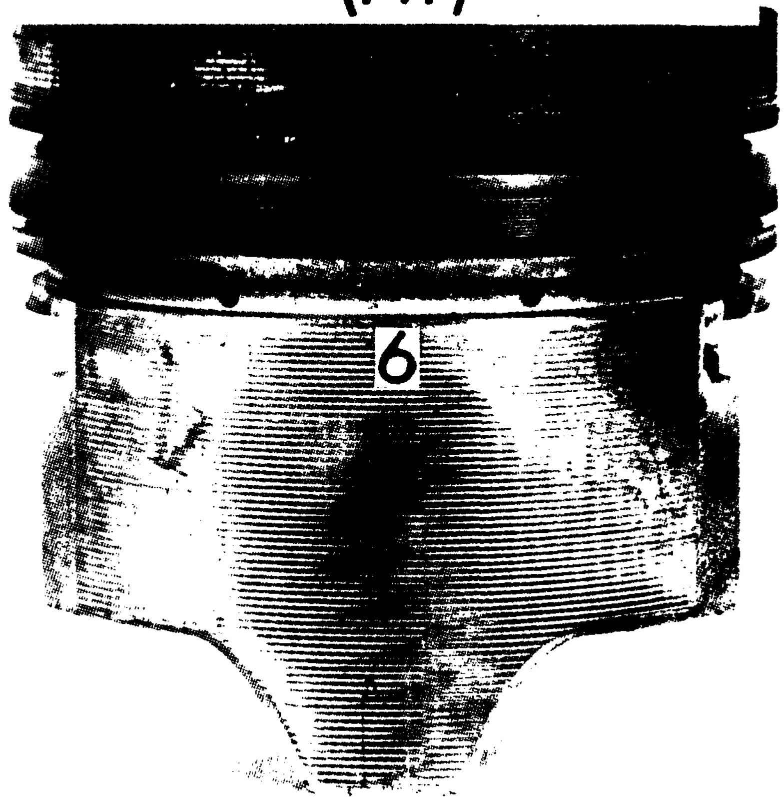
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(AT)



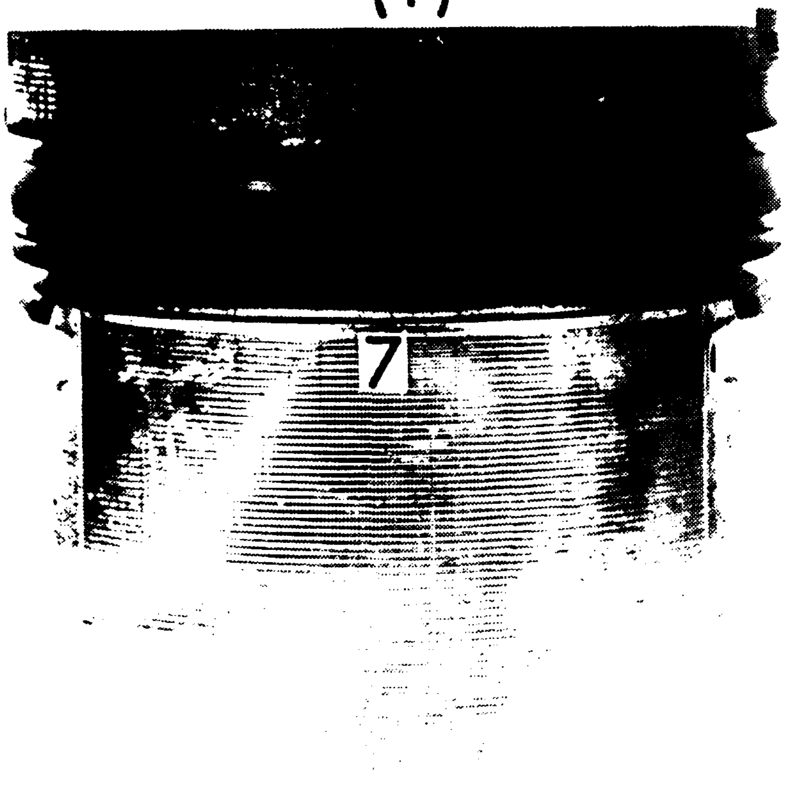
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(T)



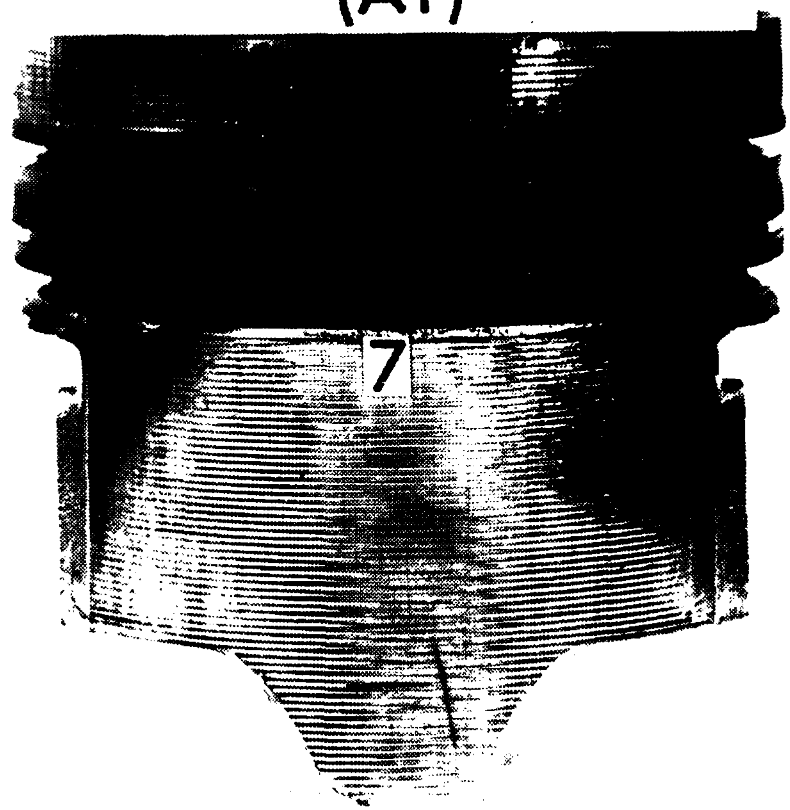
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(AT)



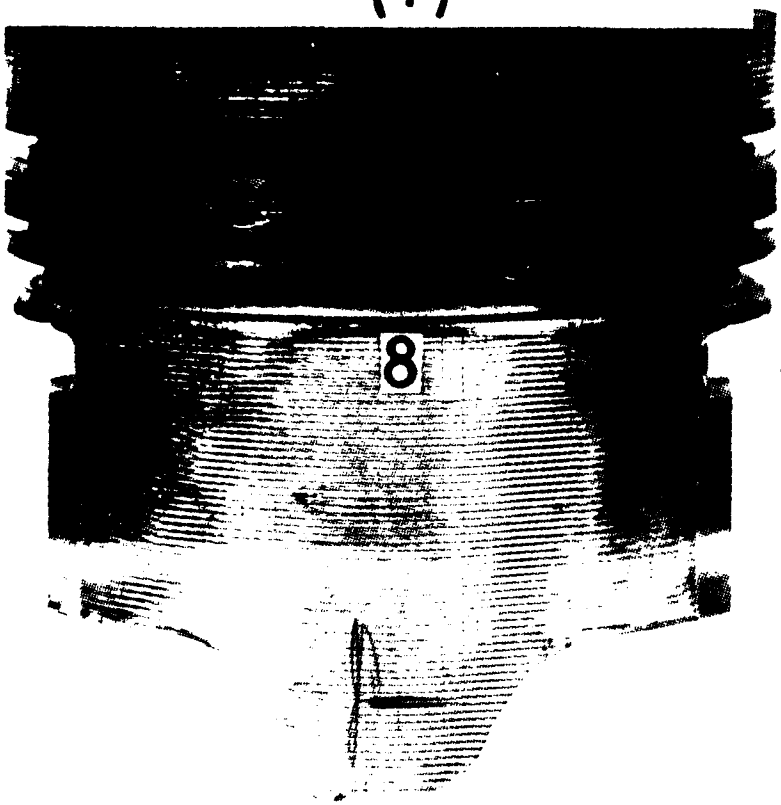
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(T)



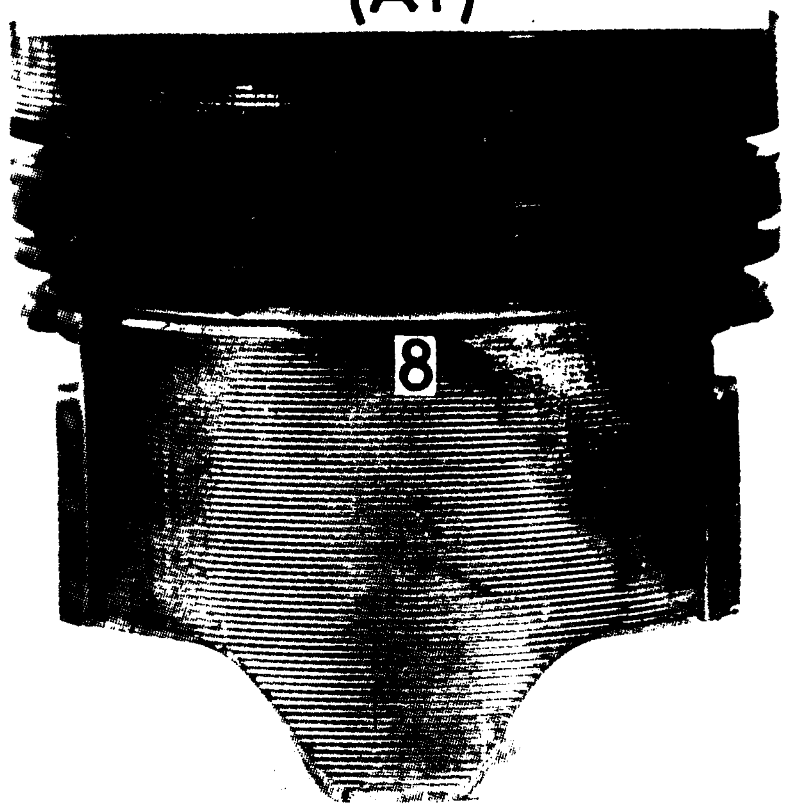
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(AT)



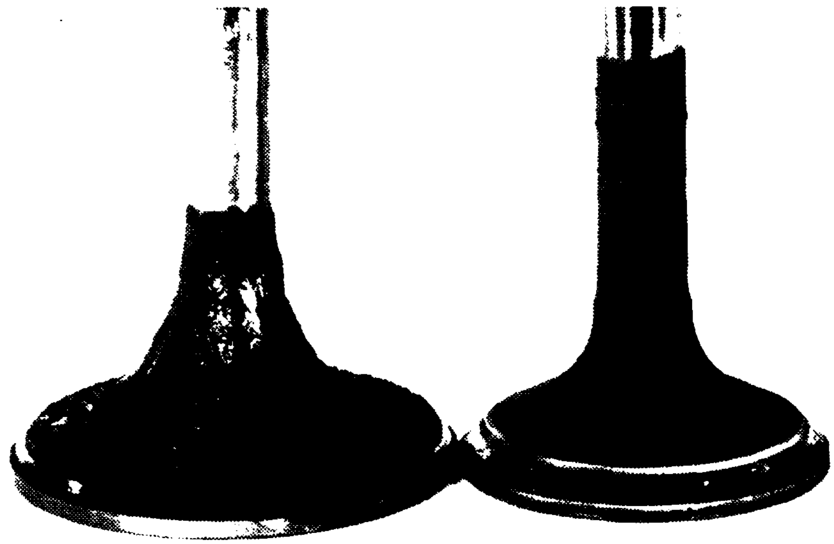
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(T)



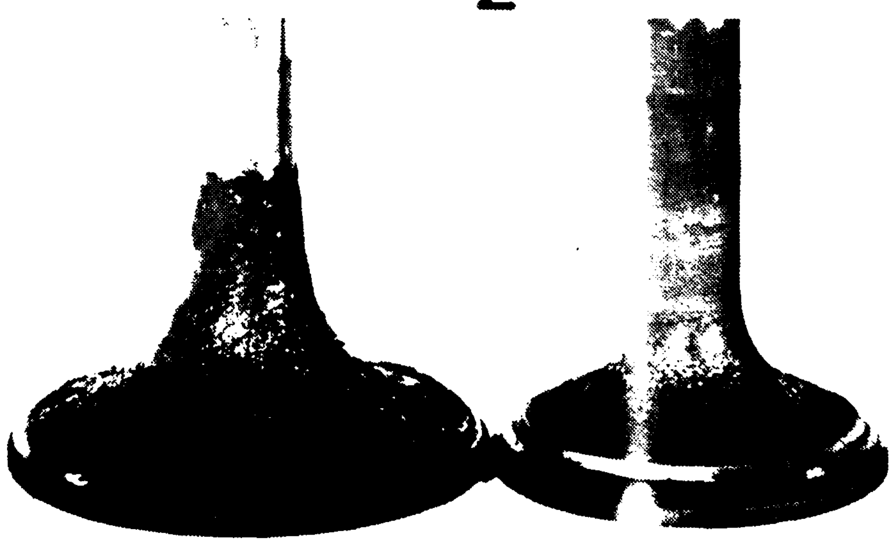
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
(AT)



G.M. 6.2 LITER TEST #1
FUEL EVALUATION
1



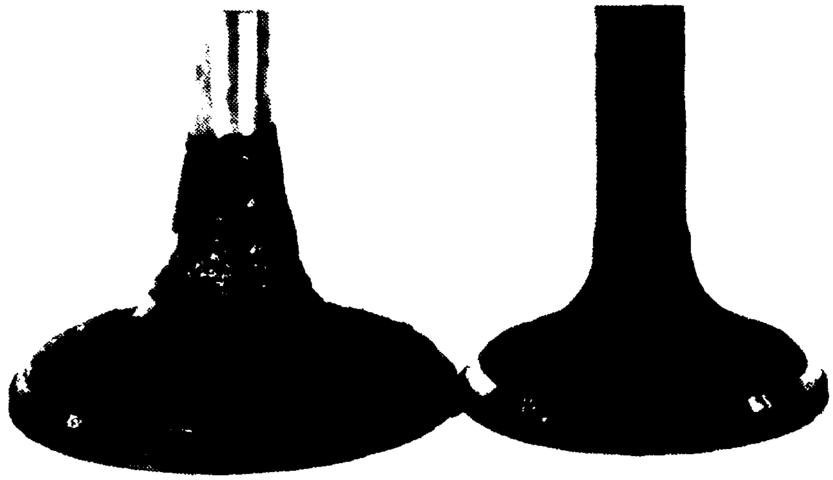
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
2



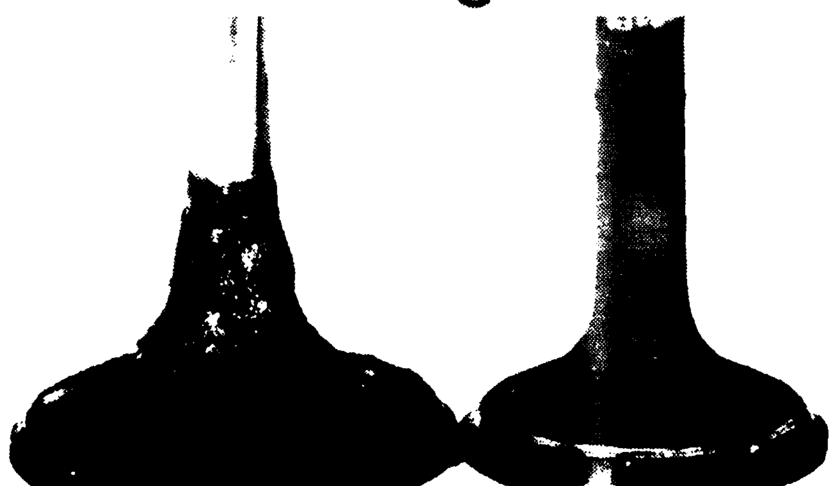
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
3

G.M. 6.2 LITER TEST #1
FUEL EVALUATION
4

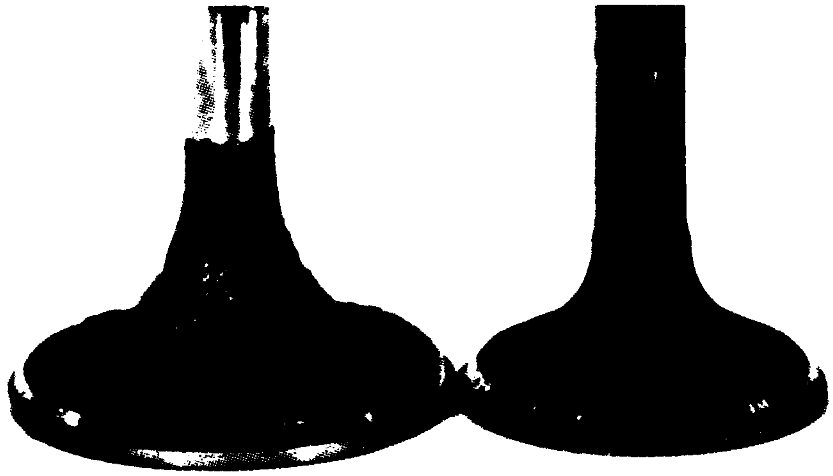
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
5



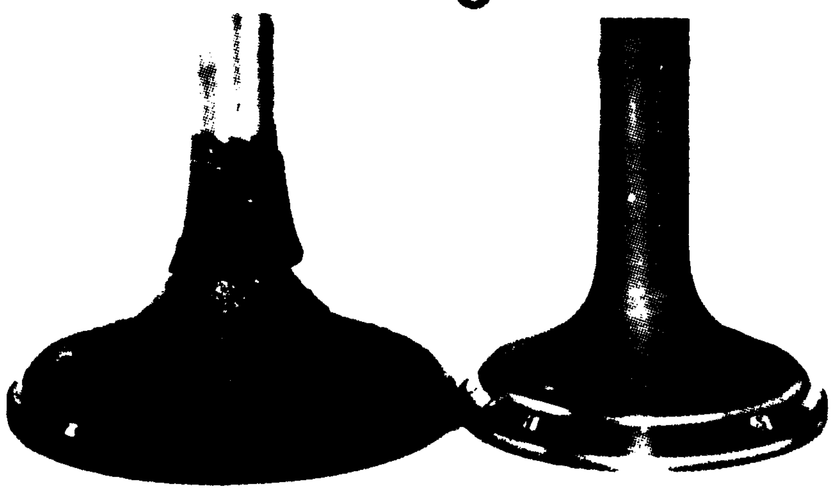
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
6

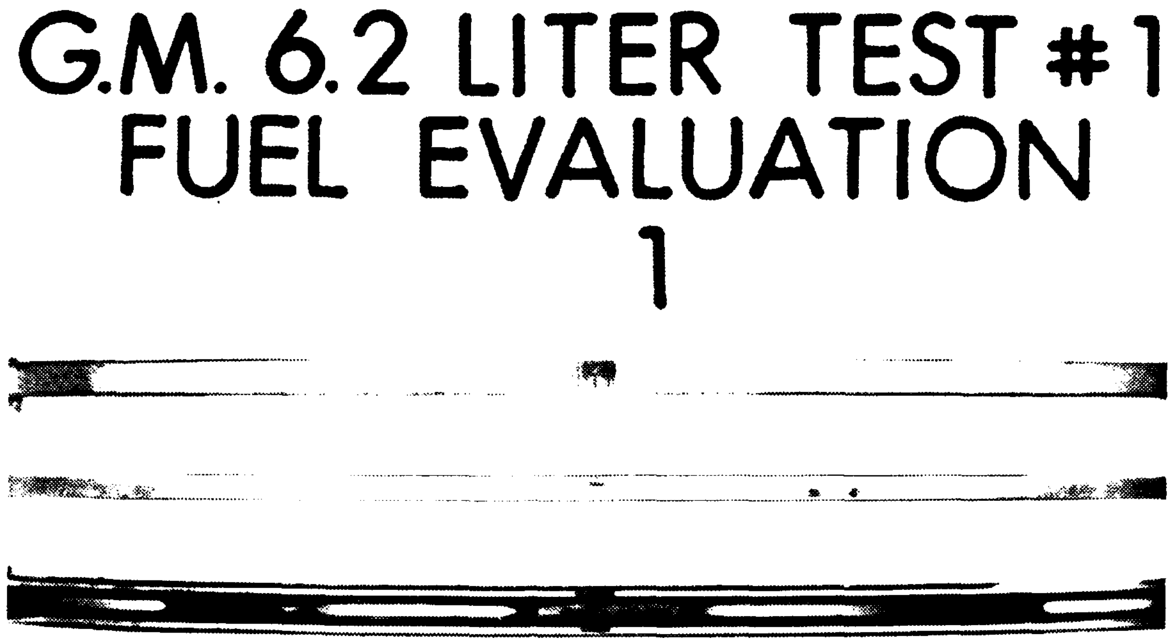


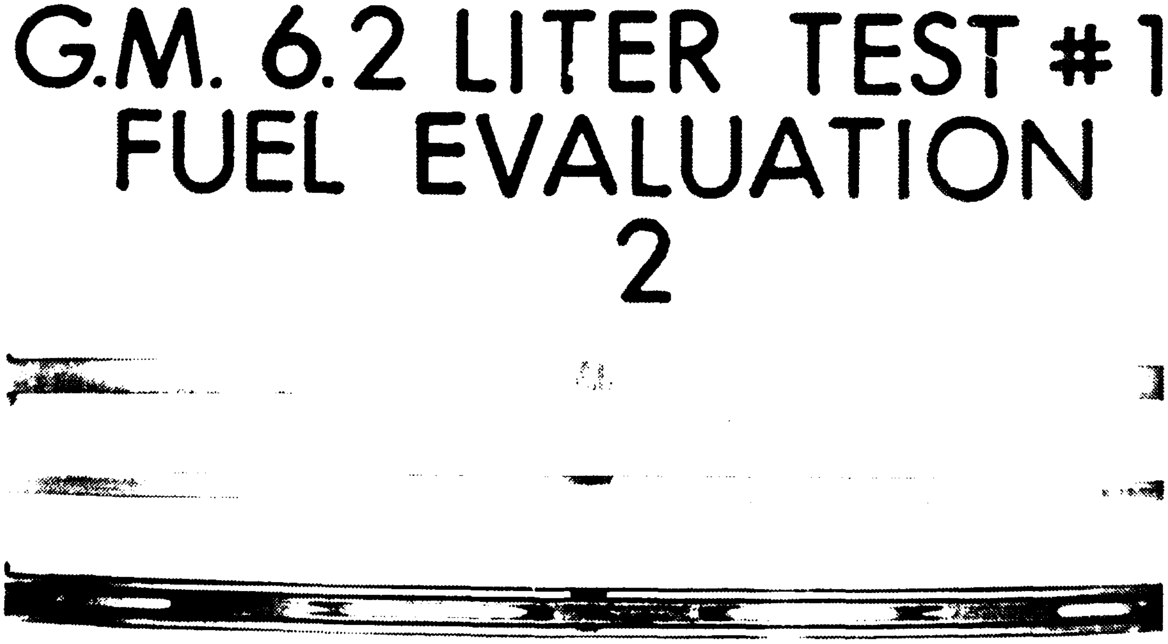
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
7



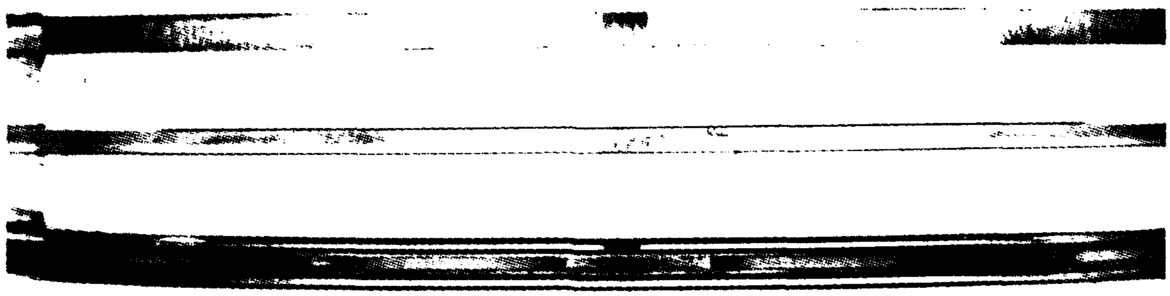
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
8



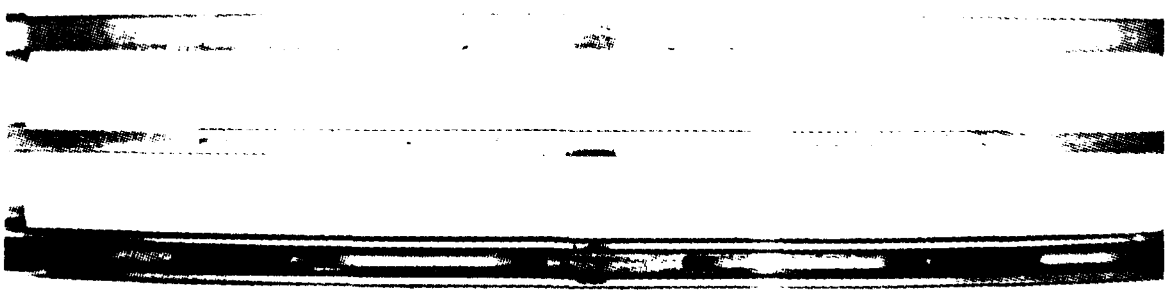

G.M. 6.2 LITER TEST #1
FUEL EVALUATION
1


G.M. 6.2 LITER TEST #1
FUEL EVALUATION
2

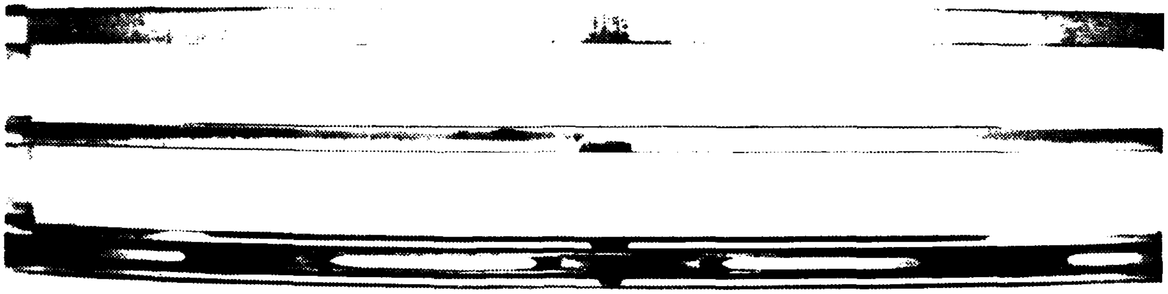
G.M. 6.2 LITER TEST #1 FUEL EVALUATION 3



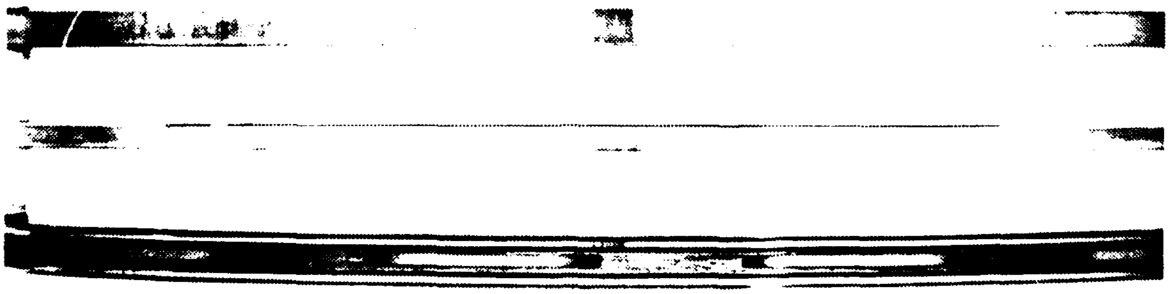
G.M. 6.2 LITER TEST #1 FUEL EVALUATION 4



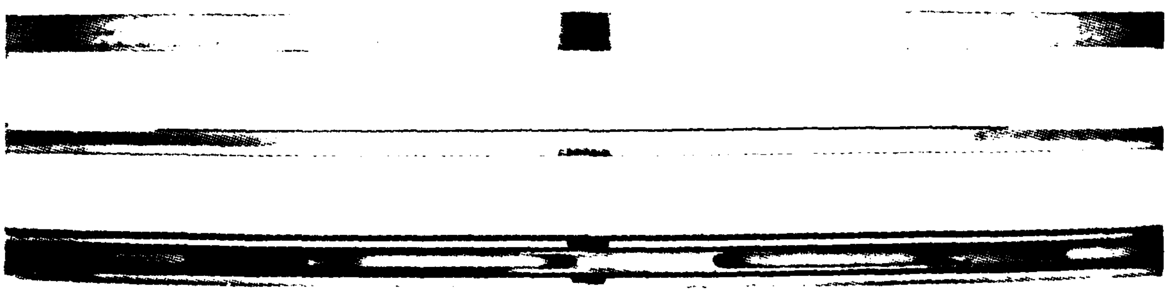
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
5



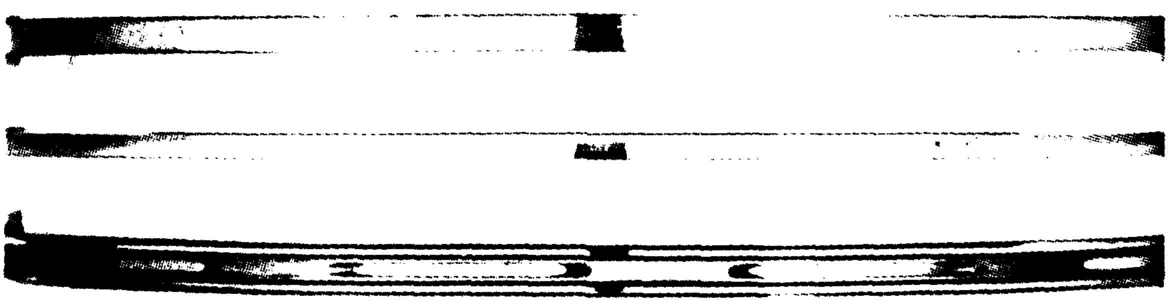
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
6

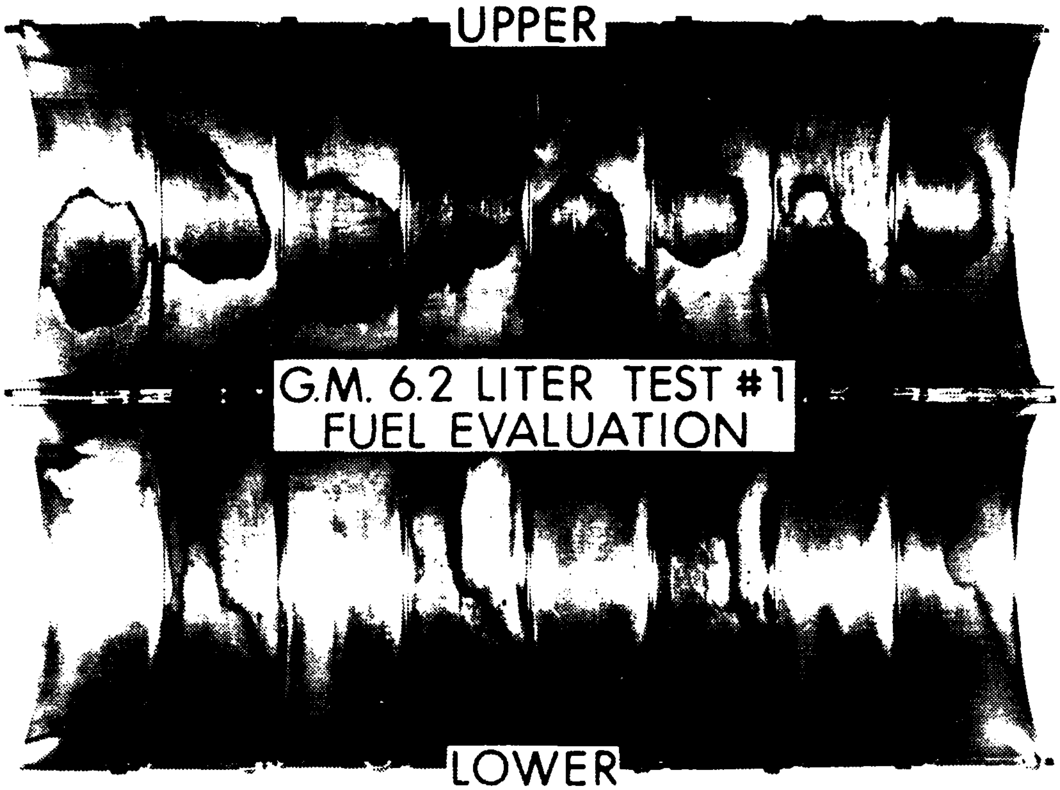


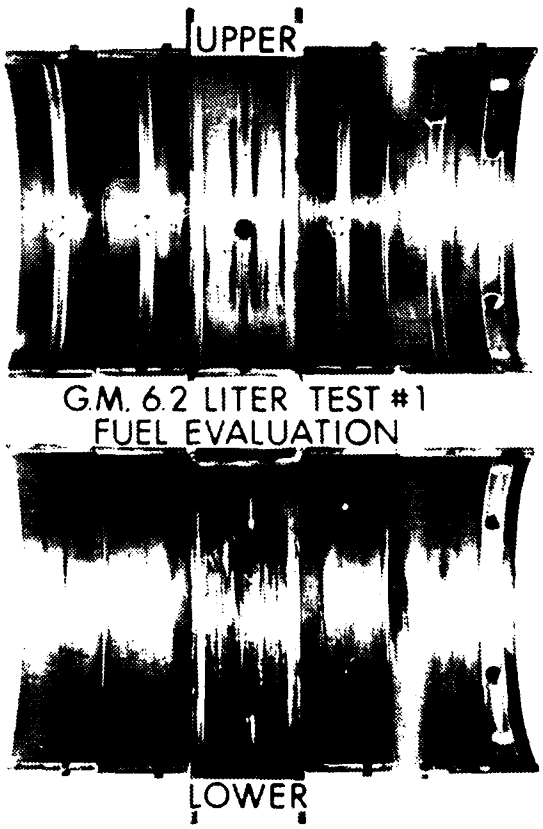
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
7



G.M. 6.2 LITER TEST #1
FUEL EVALUATION
8




UPPER
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
LOWER

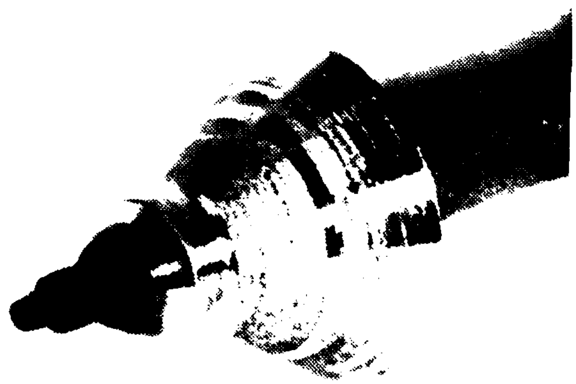

UPPER
G.M. 6.2 LITER TEST #1
FUEL EVALUATION
LOWER

1

2

3

4

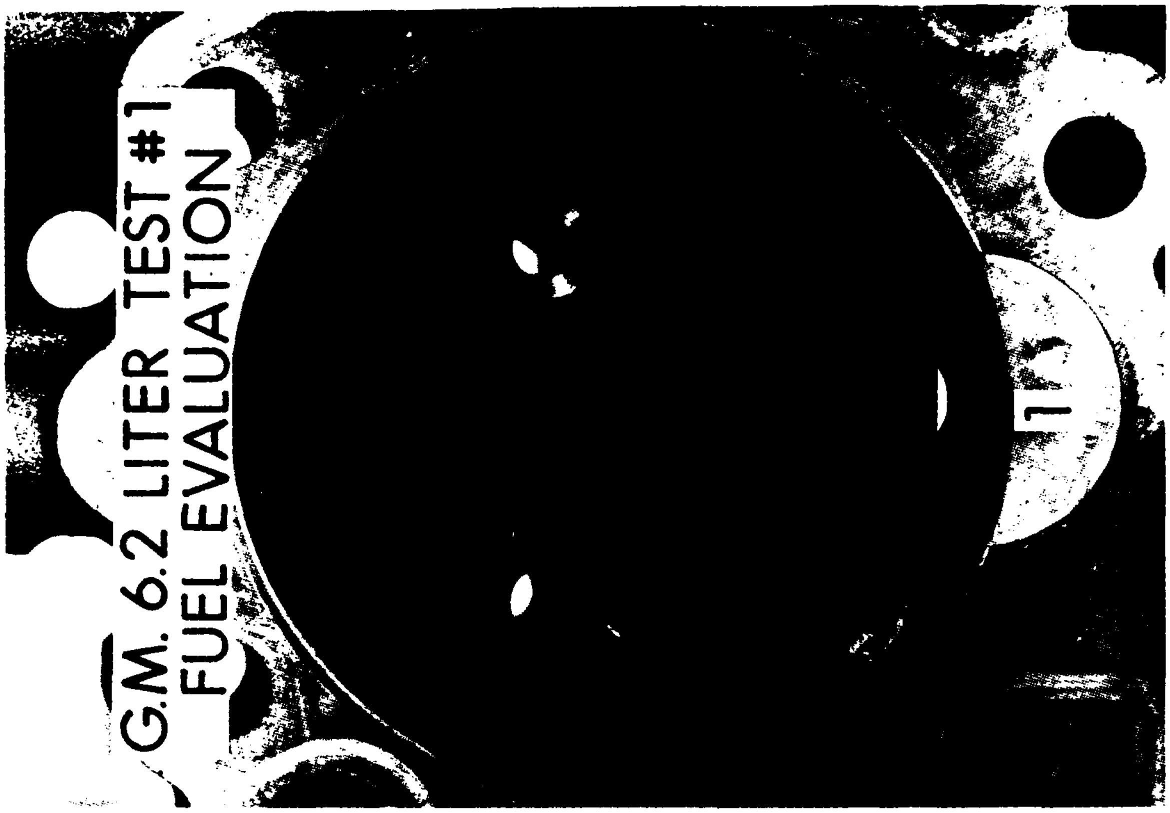


5

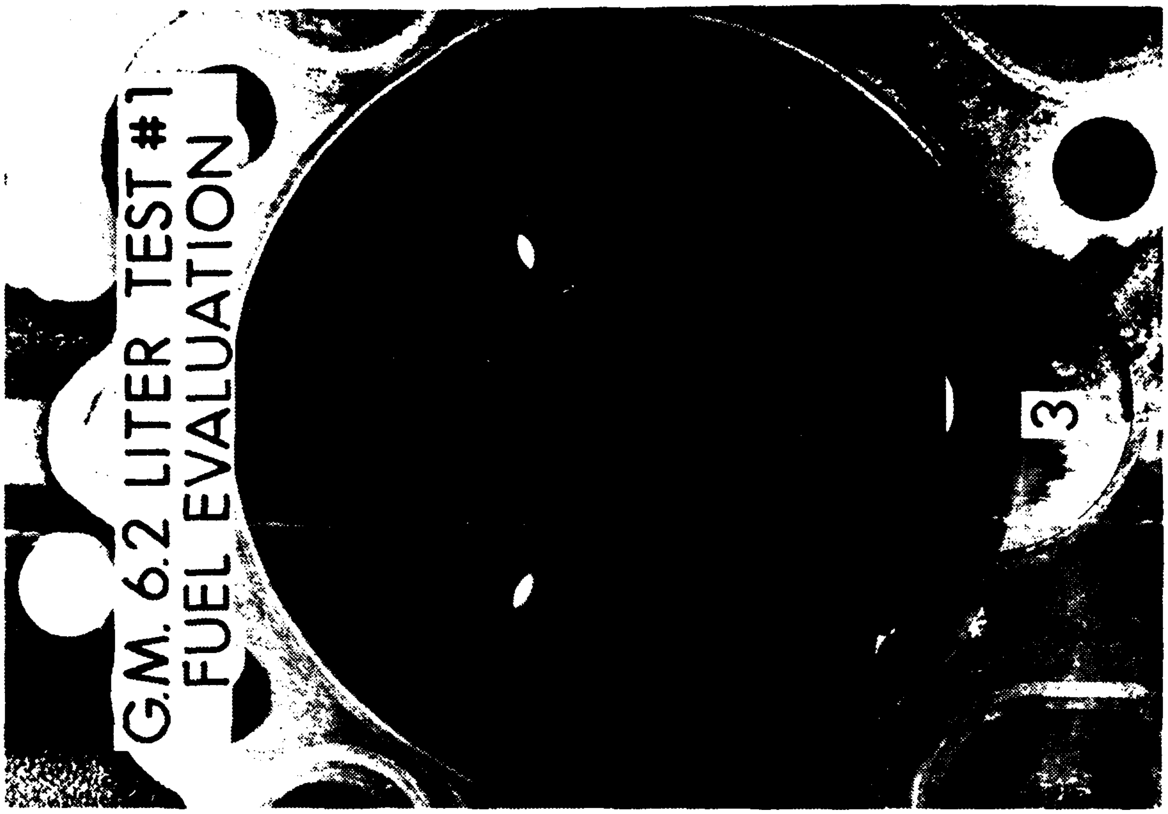
6

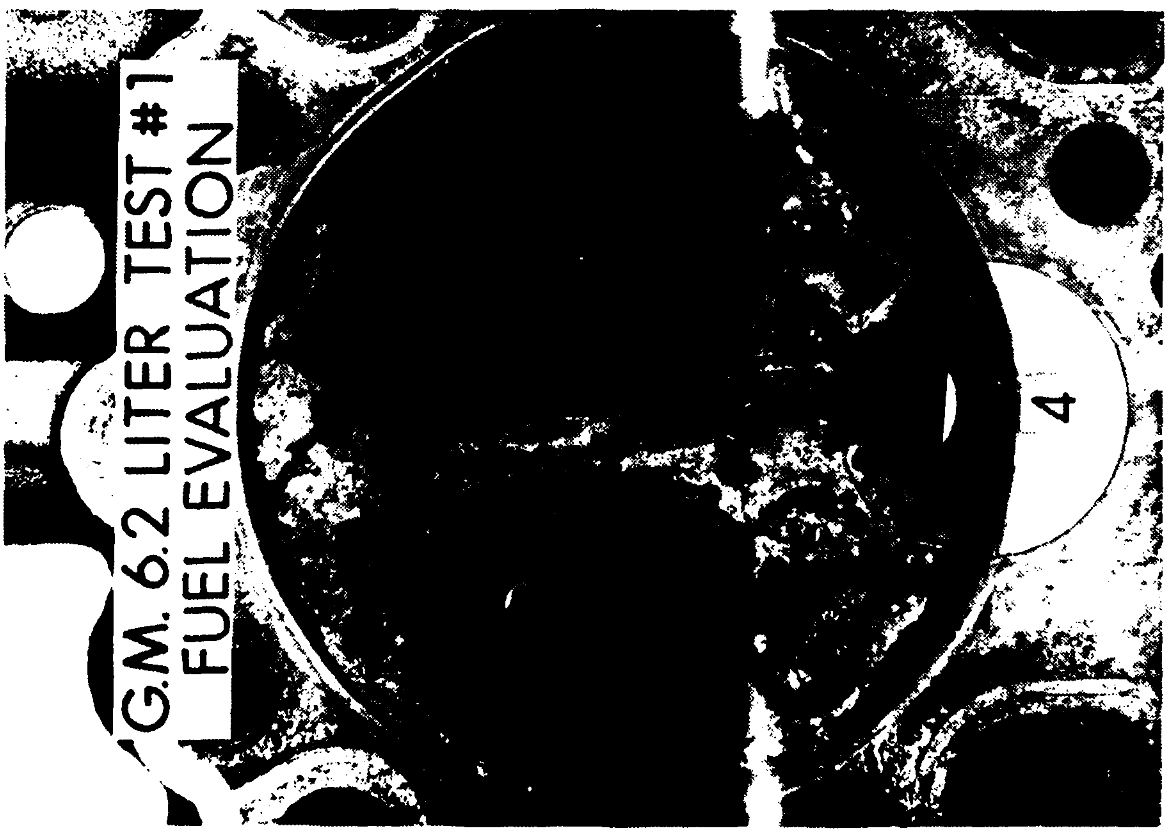
7

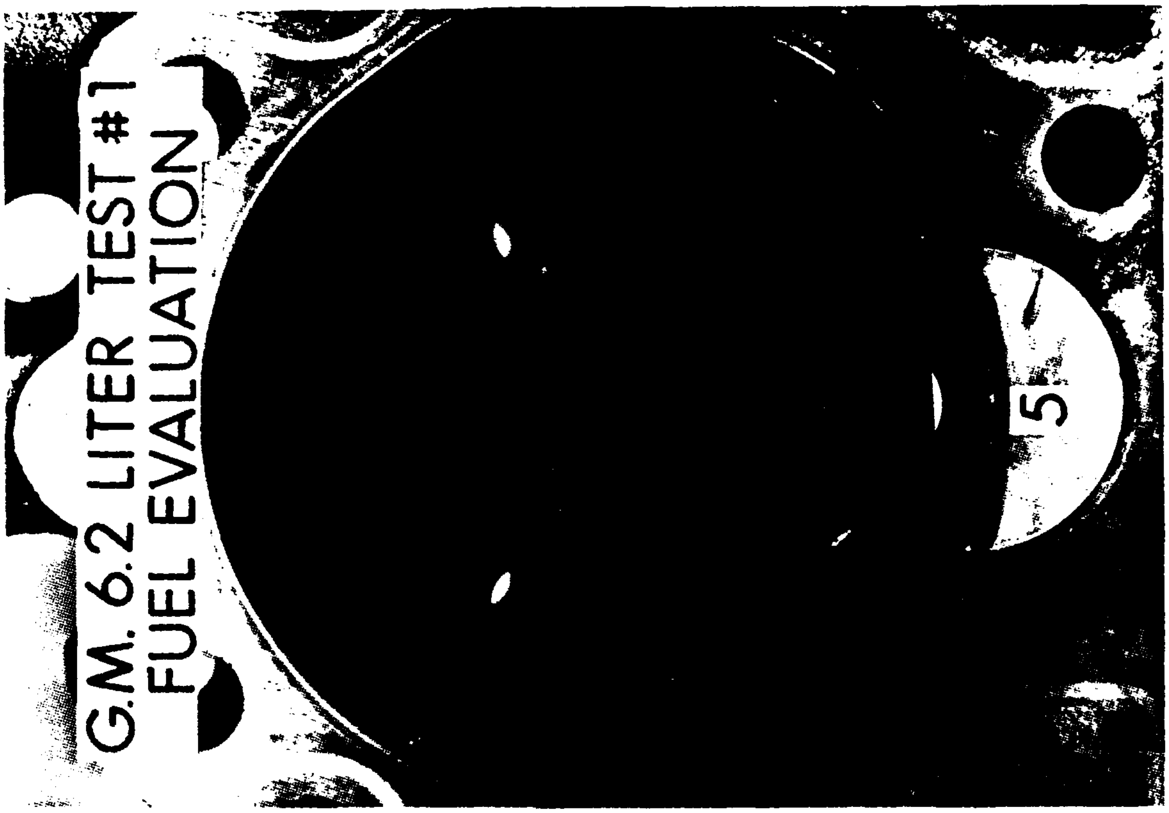
8

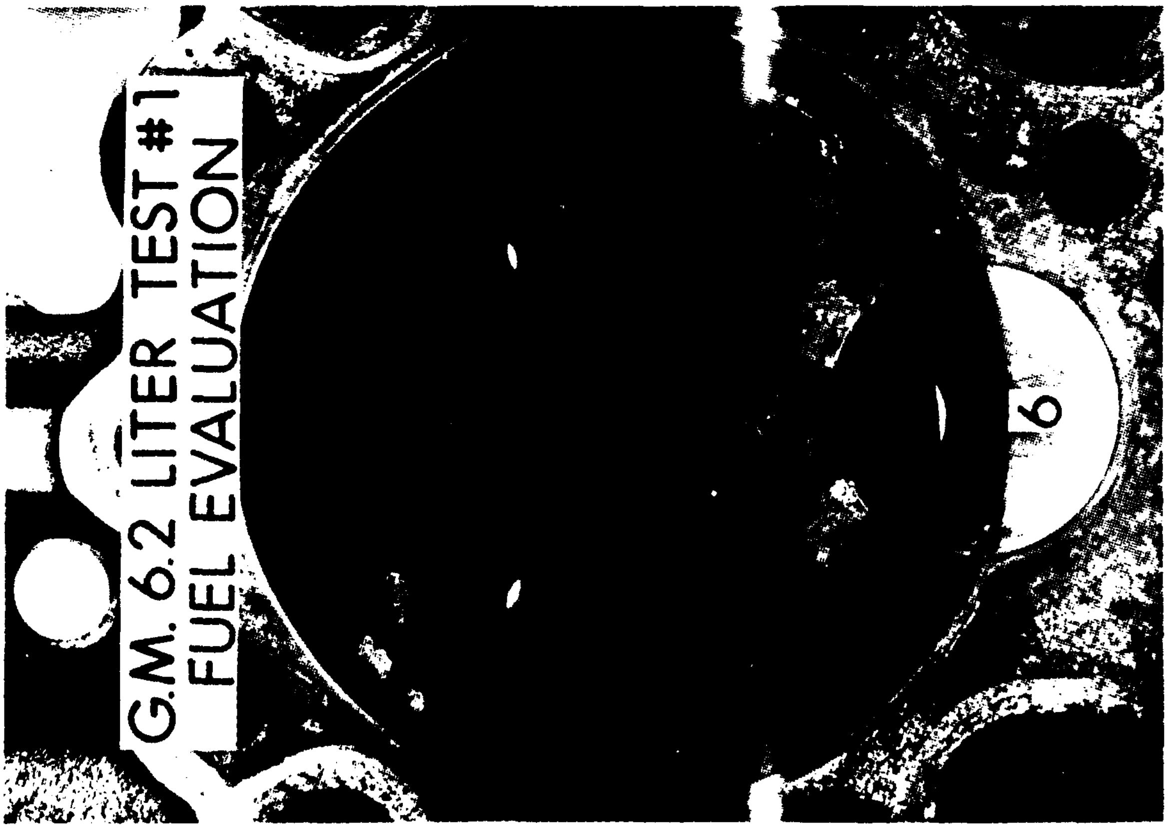

G.M. 6.2 LITER TEST #1
FUEL EVALUATION
1

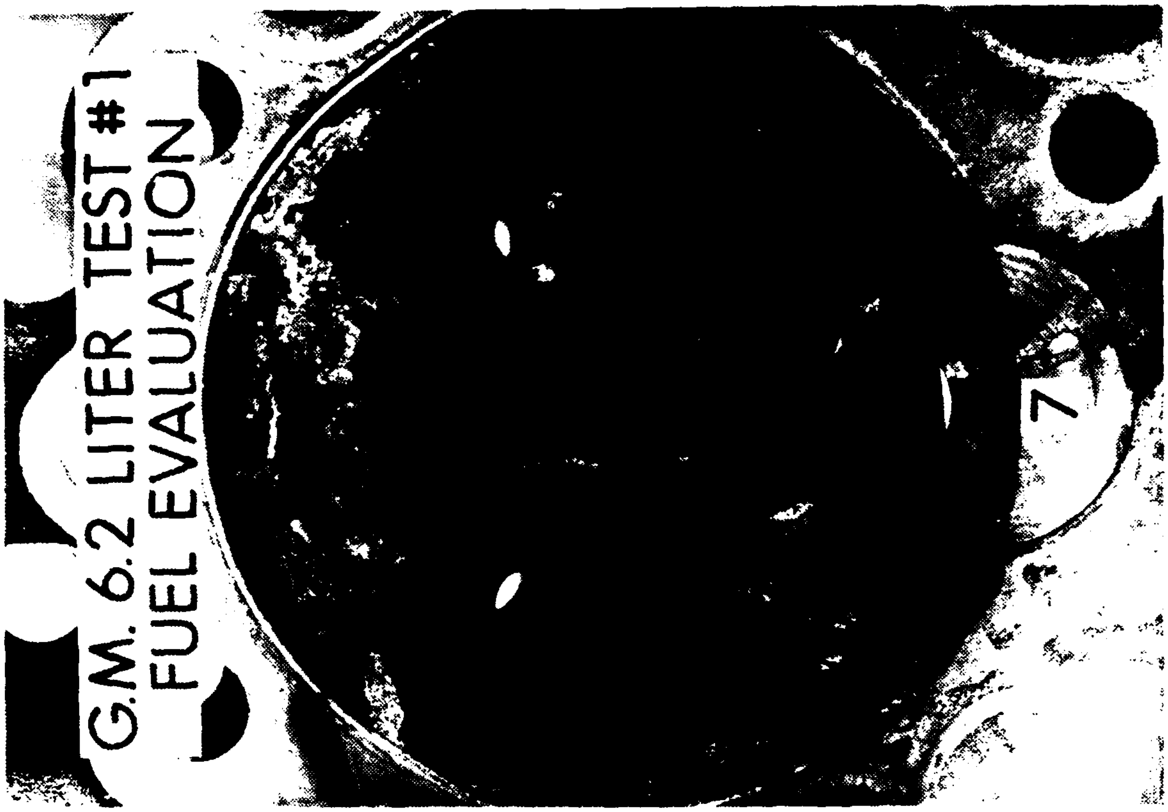

G.M. 6.2 LITER TEST #1
FUEL EVALUATION
2

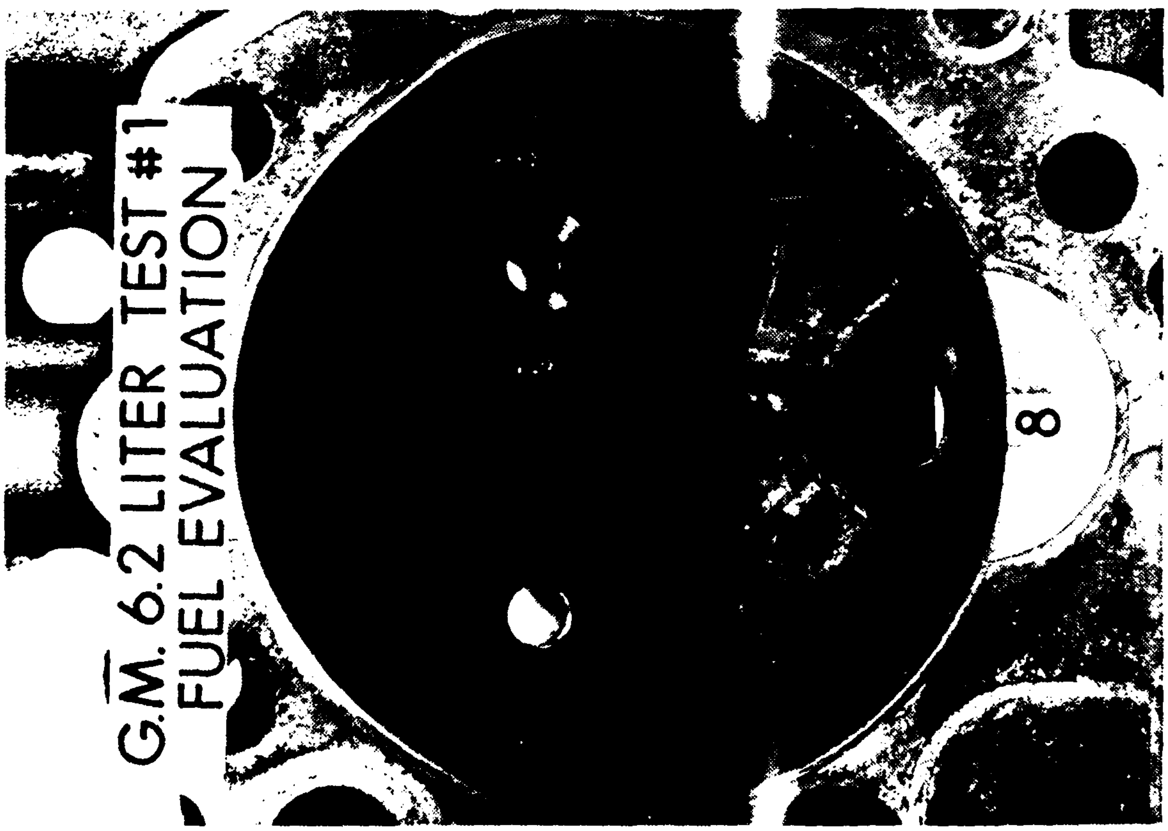

G.M. 6.2 LITER TEST #1
FUEL EVALUATION
3

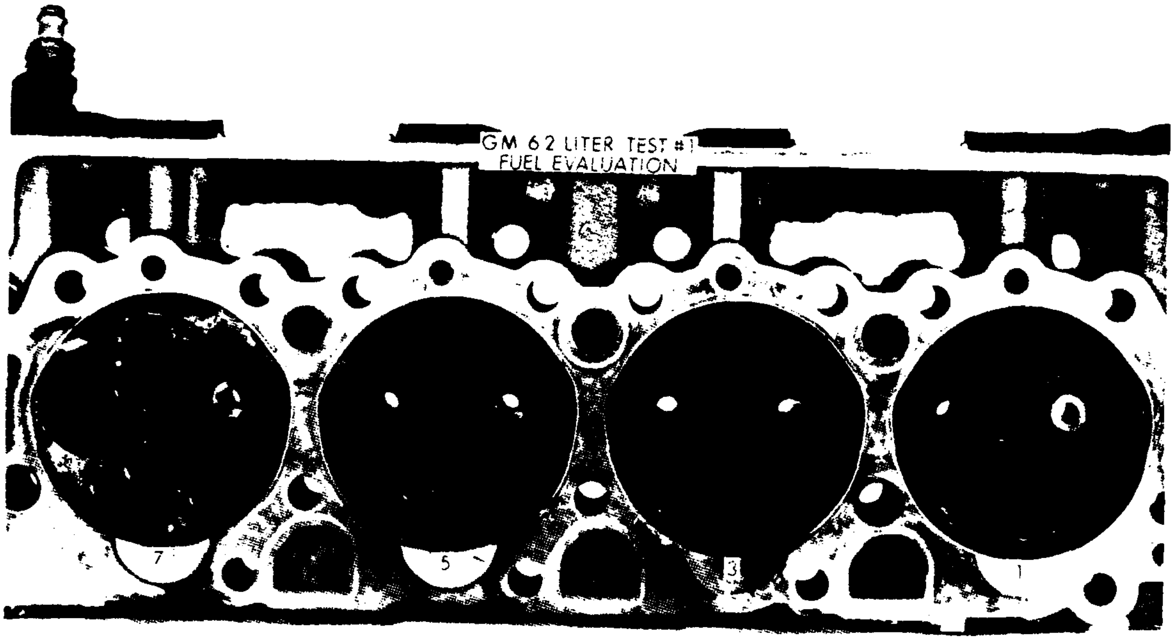

G.M. 6.2 LITER TEST #1
FUEL EVALUATION
4

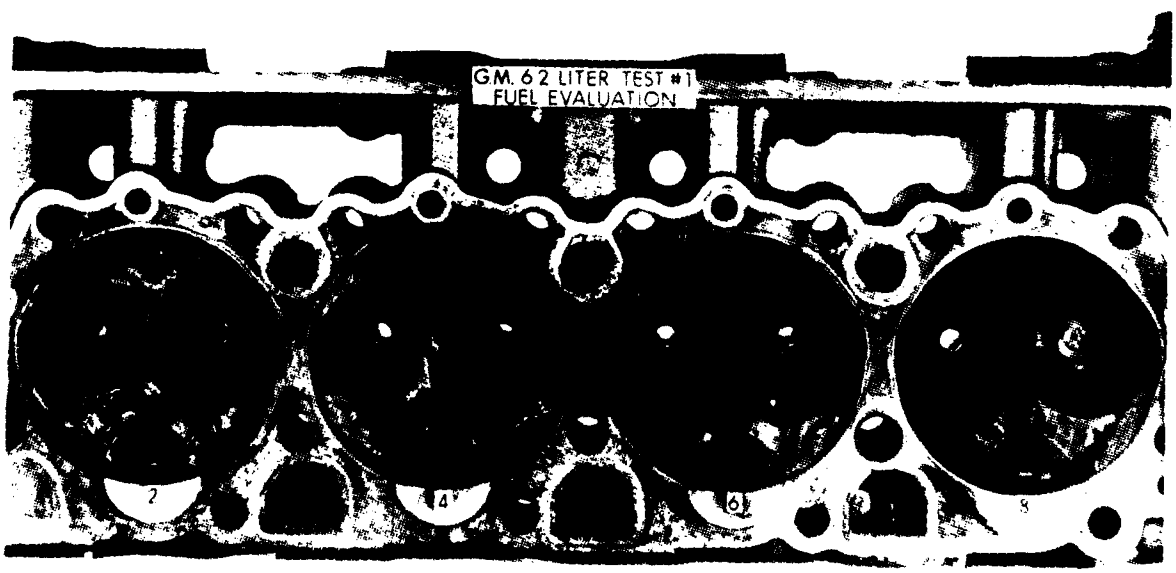

G.M. 6.2 LITER TEST #1
FUEL EVALUATION
5


G.M. 6.2 LITER TEST #1
FUEL EVALUATION
6


G.M. 6.2 LITER TEST #1
FUEL EVALUATION
7


G.M. 6.2 LITER TEST #1
FUEL EVALUATION
8


GM 6.2 LITER TEST #1
FUEL EVALUATION
7
5
3
1


G.M. 6.2 LITER TEST #1
FUEL EVALUATION
2
4
6
8

G.M. 6.2 LITER TEST #1
FUEL EVALUATION

APPENDIX B

Test Data and Photographs

GM 6.2L Engine

210-Hour Test

Cat Fuel*

Repeat Baseline

*Use of designation "Cat 1-H" test fuel refers to Reference No. 2 Diesel Fuel, or simply Cat Fuel.

GM 6.2L
CAT 1-H
LOG OF UNSCHEDULED EVENTS

Test Time, hours	Event
19	• Engine shutdown due to water leak in dynamometer
29	• Due to steadily rising maximum fuel delivery, the operator began to set the maximum load condition to 72 lb/hr fuel delivery.

GM 6.2L
CAT 1-H (TEST NO. 5)
ENGINE MEASUREMENTS

	Minimum	Maximum	Average	Specified Limits
Cylinder Bore				
Diameter	3.9781	3.9790	3.9785	3.9759 - 3.9789
Out of Round	0.0000	0.0003	0.0002	— 0.0008
Taper-Thrust	0.0002	0.0006	0.0004	— 0.0008
Piston Clearances				
Bores 1-6	0.0043	0.0060	0.0051	0.0035 - 0.0045
Bores 7-8	0.0054	0.0061	0.0058	0.0040 - 0.0050
Piston Rings				
Groove Clearance				
2nd	0.0020	0.0025	0.0023	0.0015 - 0.0030
Oil	0.0020	0.0025	0.0022	0.0016 - 0.0038
End Gap				
Top	0.027	0.034	0.031	0.0120 - 0.0220
2nd	0.045	0.047	0.046	0.0290 - 0.0390
Oil	0.027	0.033	0.031	0.0100 - 0.0200
Piston Pin				
Diameter	1.2207	1.2208	1.2208	1.2203 - 1.2206
Clearance	0.0001	0.0005	0.0003	0.0004 - 0.0006
Fit in Rod	0.0004	0.0013	0.0010	0.0003 - 0.0012
Camshaft				
Diameter	—	—	—	— —
Bearing 1-4	2.1653	2.1658	2.1655	2.1644 - 2.1663
Bearing 5	—	—	2.0079	2.0069 - 2.0088
Clearance	0.0027	0.0037	0.0032	0.0015 - 0.0040
Crankshaft				
Journal Diameter				
1-4	2.9496	2.9497	2.9497	2.9495 - 2.9504
5	—	—	2.9498	2.9493 - 2.9502
Out of Round	0.0000	0.0000	0.0000	— 0.0002 —
Clearance				
1-4	0.0035	0.0042	0.0039	0.0018 - 0.0033
5	0.0031	0.0034	0.0033	0.0022 - 0.0037
Crankpin				
Diameter	2.3979	2.3981	2.3980	2.3981 - 2.3992
Out of Round	0.0000	0.0003	0.0001	— 0.0002
Clearance	0.0032	0.0042	0.0036	0.0018 - 0.0039
Valve				
Stem Clearance				
Intake	0.0018	0.0021	0.0020	0.0010 - 0.0027
Exhaust	0.0023	0.0027	0.0026	0.0010 - 0.0027

NOTE: Measurements are in inches.

ANALYSIS OF CAT 1-H FUEL, BATCH 85-2 (AL-14069-F)

Test	AFLRL Data	Howell Data	Howell Cat 1-H Limit
Gravity, °API	34.5	34.5	32.0-35.0
Specific Gravity, 15.6/15.6°C	0.8524		
Distillation, °F(°C)			
IBP	402(206)	384(196)	Report
10% recovered	462(239)	467(242)	Report
50% recovered	517(269)	518(270)	500-530
90% recovered	611(322)	612(322)	580-620
EP	663(351)	664(351)	650-690
% recovered	99	---	(a)
% residue	1	---	(a)
Flash Point, °F(°C)	180(82)	180(82)	Report
Pour Point, °F(°C)	9(-13)	+5(-15)	+20 max
Cloud Point, °F(°C)	14(-10)	14(-10)	Report
Copper Corrosion, 3 hr at 210°F,			
Rating	1A	1A	2 max
Carbon Residue on 10% Bottoms,			
Ramsbottom wt%	0.11	0.13	0.20 max
Water and Sediment, vol%	<0.01	0.05	0.05 max
Neutralization Number, mg KOH/g	0.02	0.02	0.15 max
Ash, wt%	<0.01	0.006	0.01 max
Viscosity at 100°F (37.8°C), cSt	(b)	3.18	3.0-4.0
Viscosity at 40°C, cSt	2.98	(b)	(a)
Net Heat of Combustion, Btu/lb	18,279	(b)	(a)
MJ/kg	42,516	(b)	(a)
Cetane Number	52	51	45-51
Cetane Index	47	47	(a)
Carbon, wt%	86.24	---	(a)
Hydrogen, wt%	12.19	---	(a)
Sulfur, wt%	0.41	0.40	0.37-0.43

(a) - No requirement

(b) - Not determined

GM 6.2L ENGINE
OPERATING CONDITIONS SUMMARY
LUBRICANT: AL-14080-L
CAT 1-H FUEL AL-14069-F
(TEST NO. 5)

	Full Power Mode (3600 rpm)		Idle Mode (800 rpm)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed (rpm)	3602	3.814	926	64.730
Torque (ft-lb)	202	15.51	0.4	0.5
Fuel Consumption (lb/hr)	72.0	0.735	2.7	1.7
Observed Power (Bhp)	137	10.66	--	--
BSFC (lb/Bhp-hr)	0.547	0.038	--	--
Temperature (°F)				
Water Jacket Inlet	168	6.27	96	9.13
Water Jacket Outlet	179	6.62	101	3.70
Oil Sump	240	8.43	141	9.18
Fuel Inlet	86	4.7	81	8.7
Air Inlet	93	8.0	77	8.4
Exhaust Temperature (°F)				
Cylinder 1	1200	90.75	170	7.97
Cylinder 2	1289	90.18	157	12.12
Cylinder 3	1269	96.25	161	8.17
Cylinder 4	1303	94.04	179	9.01
Cylinder 5	1296	138.50	176	9.15
Cylinder 6	1232	103.68	201	9.97
Cylinder 7	1184	87.51	179	13.36
Cylinder 8	1224	129.42	173	8.49
Common	1190	87.57	158	5.81

GM 6.2L
CAT 1-H (TEST NO. 5)
WEAR METALS BY XRF
LUBRICANT: AL-14080-L

Test Time, hours	Wear Metals, ppm Fe	Cu	Cr	Pb	S%
0	--	--	--	--	--
14	52	17	15	60	.44
28	142	30	15	60	.60
42	157	42	15	60	.56
56	157	37	15	60	.51
70	177	40	15	60	.49
84	136	26	15	60	.51
98	180	32	15	60	.52
112	183	32	15	102	.53
126	177	31	15	130	.55
140	231	32	15	113	.54
154	199	24	15	155	.55
168	196	27	15	103	.54
182	194	30	15	103	.54
196	198	37	15	79	.55
210	208	34	15	96	.52

GM 6.2L
CAT 1-H (TEST NO. 5)
LUBRICANT: AL-14080

	ASTM Method	Test Time, hours 0	70	140	210
Kinematic Viscosity at 40°C, cSt	D 445	--	185.20	253.55	223.62
Kinematic Viscosity at 100°C, cSt	D 445	--	18.55	23.20	21.97
Total Acid Number, mg KOH/g	D 669	--	8.16	9.41	9.65
Total Base Number, mg KOH/g	D 669	--	1.39	1.12	1.92
Pentane B Insolubles, wt%	D 893	--	4.33	6.07	6.14
Toluene B Insolubles, wt%	D 893	--	3.91	5.39	5.49
Flash Point, °C	D 92	--	460	460	480

GM 6.2L
CAT 1-H (TEST NO. 5)
WEAR MEASUREMENTS

Cylinder Bore Diameter Change

	1		3		5		7	
	T-AT	F-B	T-AT	F-B	T-AT	F-B	T-AT	F-B
Top	0.0001	0.0000	0.0000	0.0003	-0.0001	0.0000	0.0001	0.0002
Middle	-0.0003	-0.0002	0.0002	0.0001	0.0001	0.0009	0.0001	0.0001
Bottom	0.0001	0.0000	-0.0001	0.0000	-0.0001	0.0002	-0.0002	-0.0001

	2		4		6		8	
	T-AT	F-B	T-AT	F-B	T-AT	F-B	T-AT	F-B
Top	-0.0002	0.0006	-0.0002	-0.0001	-0.0001	0.0002	0.0001	0.0000
Middle	-0.0001	-0.0004	0.0002	0.0000	0.0001	0.0000	0.0003	0.0000
Bottom	0.0000	-0.0002	0.0000	-0.0001	0.0001	0.0000	0.0001	0.0001

Average Change

	T-AT	F-B
Top	-0.0001	0.0002
Middle	0.0001	0.0001
Bottom	-0.0001	0.0000

Overall Average Change: 0.0001

Piston Ring End Gap Change

Ring	1	2	3	4	5	6	7	8	Average Change
Top	0.002	0.002	0.002	0.003	0.003	0.001	0.003	0.002	0.002
2nd	0.000	0.001	0.000	0.000	0.001	0.000	0.002	0.001	0.001
Oil	0.001	0.001	0.002	0.003	0.002	0.002	0.002	0.001	0.002

Overall Average: 0.002

Keystone Top Ring Proudness

-0.0019	0.0014	0.006	0.0022	0.0048	0.001	0.0020	0.0039	0.0024

Bearing Weight Change

Main Bearings									
Upper	0.1392	0.0862	0.0574	0.038	0.0724	----	----	----	0.0786
Lower	0.0376	0.0562	0.0734	0.0425	0.0678	----	----	----	0.0555
Rod Bearings									
Upper	0.1622	0.169	0.1643	0.1828	0.1788	0.2011	0.1743	0.1676	0.1750
Lower	0.1345	0.1446	0.1482	0.1383	0.1328	0.1553	0.1522	0.1367	0.1428

Overall Average: 0.1589 grams

Valve Recession

Intake	0.0021	0.0000	-0.0014	-0.0037	-0.0023	0.0001	-0.0057	0.0007	-0.0013	-0.0012
Exhaust	0.0011	0.0003	0.0013	-0.002	-0.002	-0.0016	-0.0027	-0.0025	-0.0010	

Overall Average: -0.0012

NOTE: Measurements are in inches.

GM 6.2L
CAT 1-H (TEST NO. 5)
POST TEST ENGINE CONDITION AND DEPOSITS

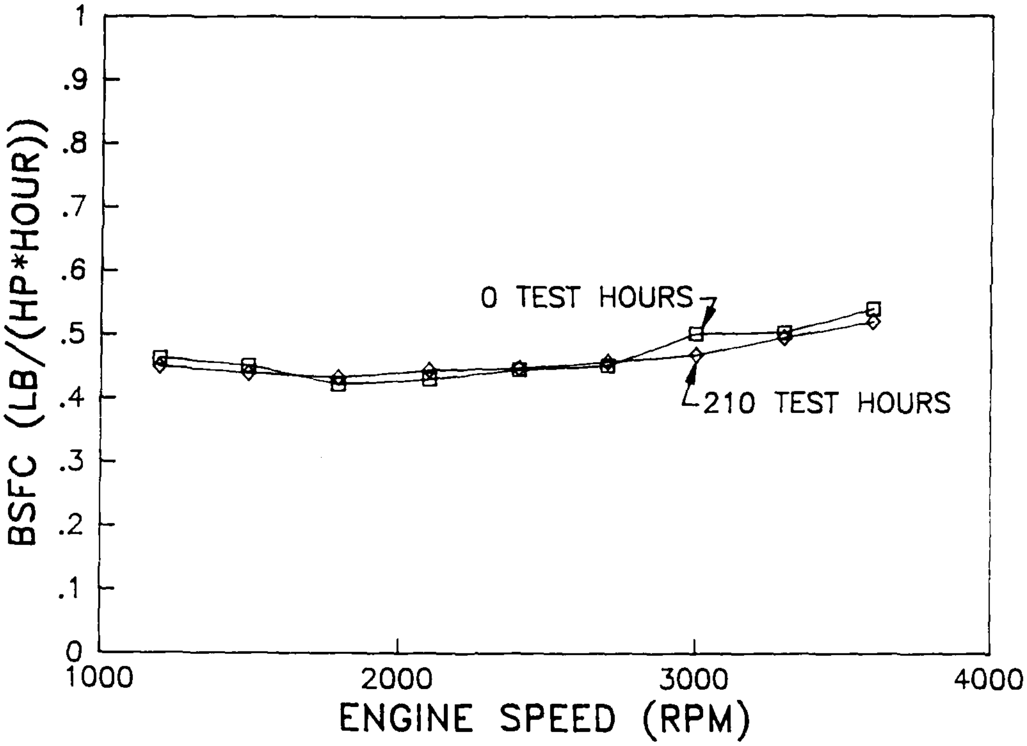
	1	2	3	4	5	6	7	8	Average
Cylinder Liner									
Liner Scuffing, % Area									
Thrust	0	0	0	0	0	0	0	0	0
Anti-Thrust	0	0	0	0	0	0	0	0	0
% Total Area	0	0	0	0	0	0	0	0	0
								Overall:	0
Liner Polished, % Area									
Thrust	0	0	0	0	0	0	0	0	0
Anti-Thrust	0	0	0	0	0	0	0	0	0
% Total Area	0	0	0	0	0	0	0	0	0
								Overall:	0
Pistons									
Ring Face Distress Demerits									
Top	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.3125
2nd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
								Overall:	0.1563
Piston Skirt Rating									
Thrust	LS*	LS	LS	LS	S*	LS	LS	LS	----
Anti-Thrust	LS	LS	LS	LS	N*	LS	LS	LS	----
Piston WTD Rating	94.13	85.63	83.00	95.13	99.50	83.63	89.63	87.75	89.80
Exhaust Valves									
Deposits									
Head					1/4 ASC**				
Face	----	----	----	----	----	----	----	----	----
Tulip	0.5	0.5	1.1	0.75	1.2	1.4	1.1	0.5	----
Stem	----	----	----	----	----	----	----	----	----
Surface Condition									
Freeness in Guide					Free				
Head					Normal				
Face					Normal				
Seat					Normal				
Stem					Normal				
Tip					Normal				
Other Ratings									
Prechamber Deposits (grams)	0.0033	0.0029	0.0043	0.0042	0.0062	0.0028	0.0092	0.002	0.0043
Combustion Chamber Deposits (grams)	0.2181	0.1361	0.4007	0.2383	0.2514	0.222	0.36	0.2201	0.2558
Bearing Surface					Normal				

* LS - lightly scratched, S - scratched, N - normal.
** 1/4 ASC/ soft carbon, prefix indicates carbon depth with 1/4 ASC being the least to 3 the most.

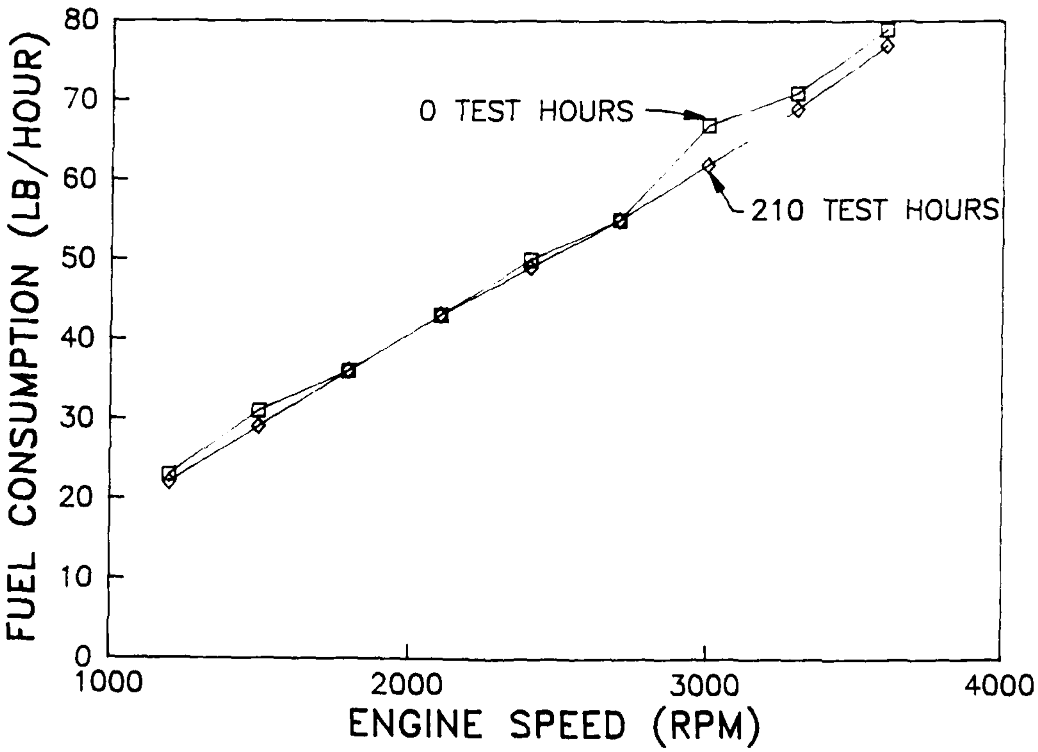
GM 6.2L
CAT 1-H
FUEL INJECTOR AND PUMP TESTS
ENGINE SERIAL NUMBER: DJ-921

	Cylinder Number								
	1	2	3	4	5	6	7	8	Average
Pop-Off Pressure (psi)									
Before Test	1700	1700	1700	1700	1775	1700	1700	1825	1725
After Test	1525	1640	1440	1600	1625	1500	1575	1475	1547.5
	Overall Decrease: 177.5 psi								
Fuel Pump Calibration									
mL/min at 1000 rpm									
Before Test	46.0	45.5	47.0	48.5	45.0	47.0	47.0	45.0	46.3
After Test	46.0	46.5	48.0	48.0	46.5	46.5	47.0	48.0	47.1
	Overall Decrease: 0.8 mL/min								
mL/min at 1800 rpm									
Before Test	40.0	44.0	44.0	48.0	42.5	44.0	43.0	43.5	43.6
After Test	47.0	48.5	50.0	53.0	47.5	48.0	47.5	48.3	48.7
	Overall Decrease: 5.1 mL/min								

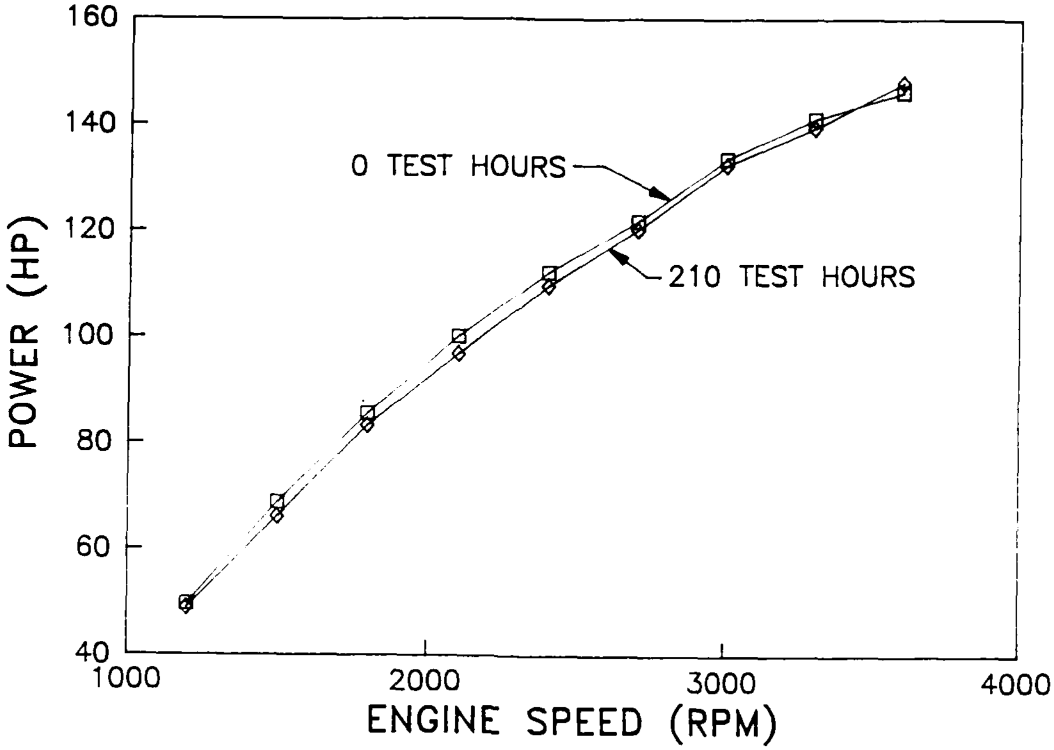
FULL LOAD BSFC CURVES

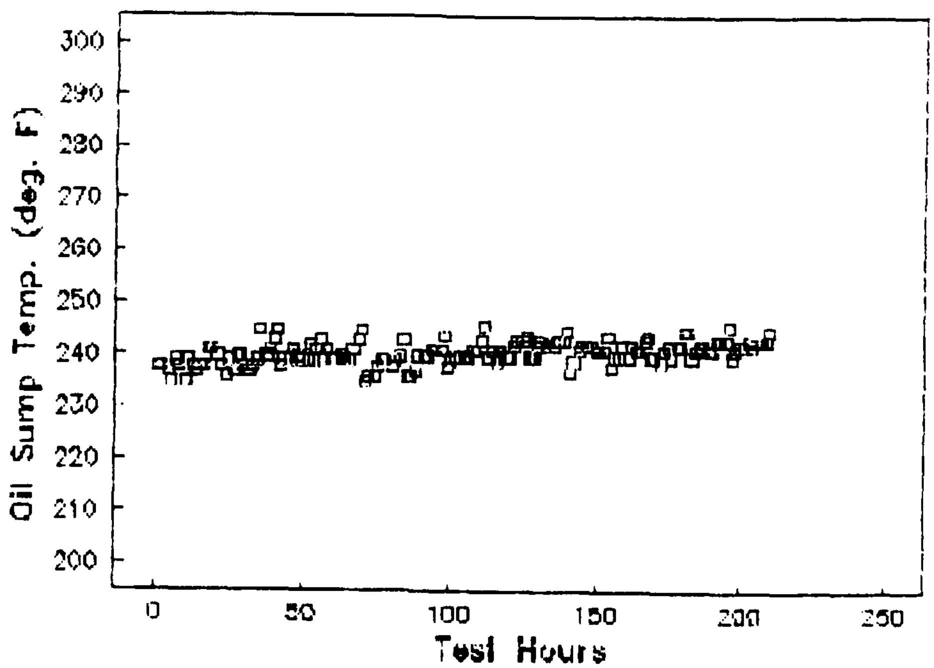


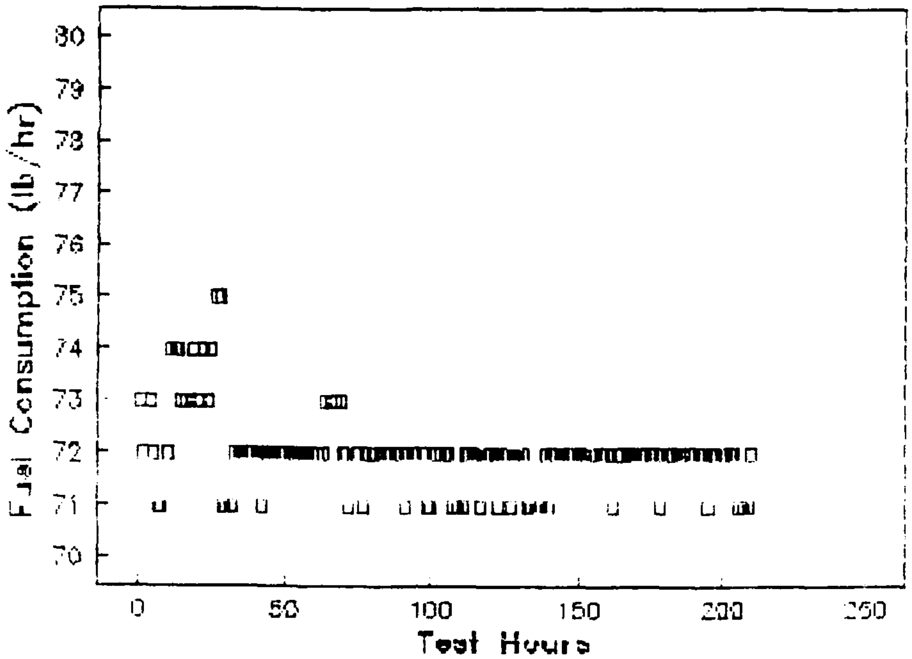
FULL LOAD FUEL CONSUMPTION



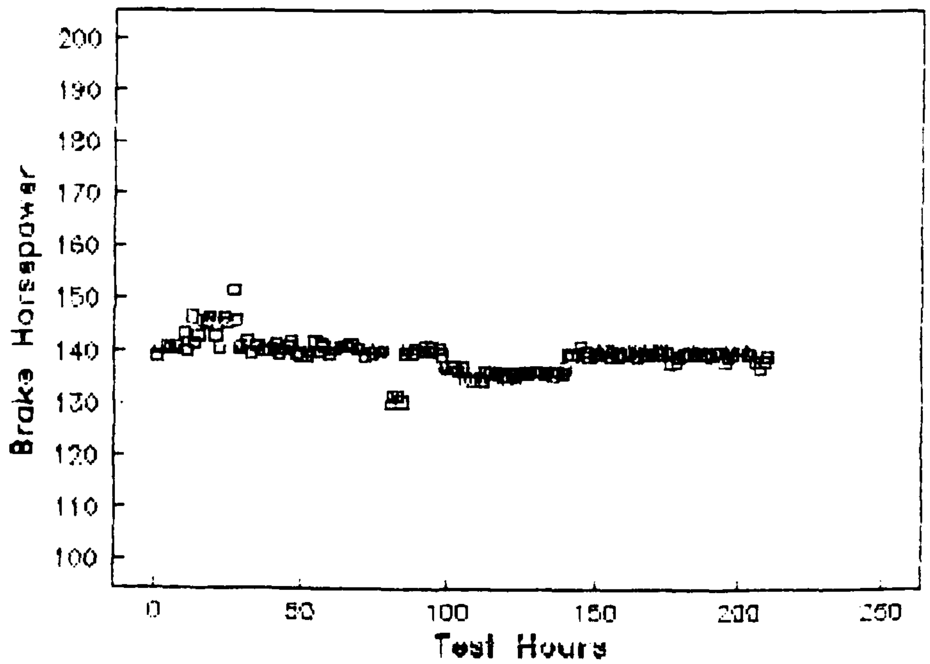
FULL LOAD POWER CURVES



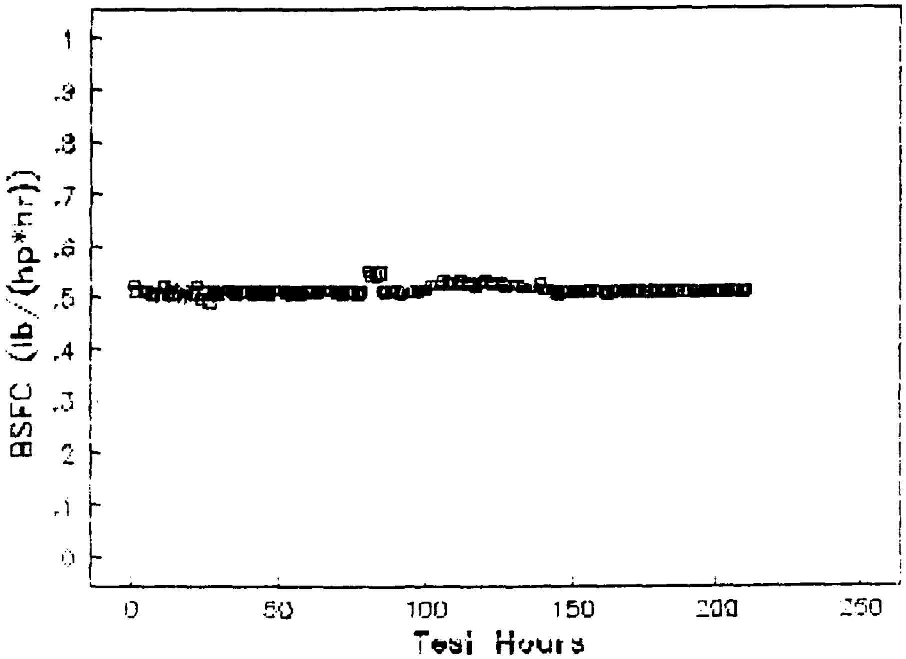




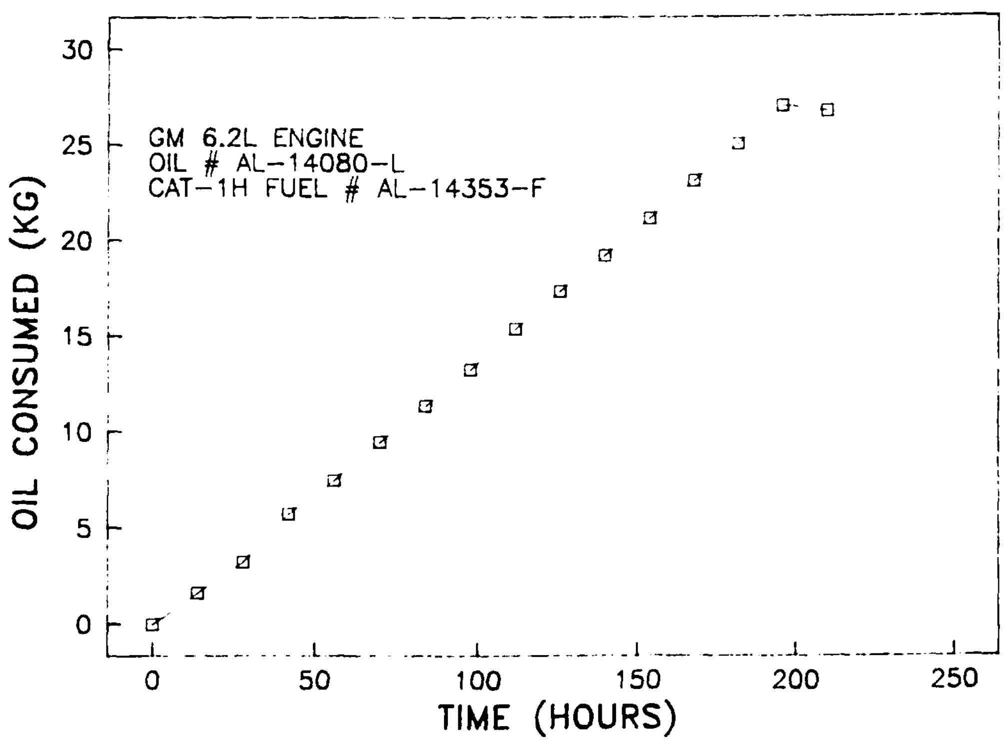
Fuel Consumption (lb/hr)
80
79
78
77
76
75
74
73
72
71
70
0
50
100
150
200
250
Test Hours

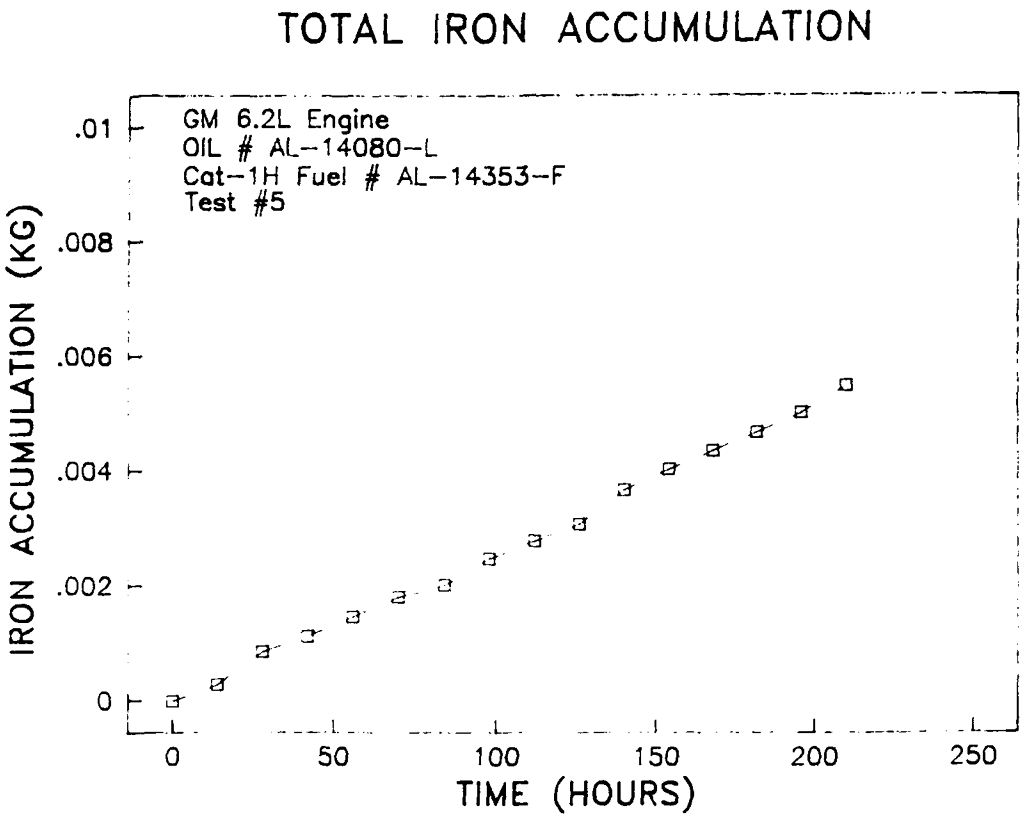


Brake Horsepower
200
190
180
170
160
150
140
130
120
110
100
0
50
100
150
200
250
Test Hours

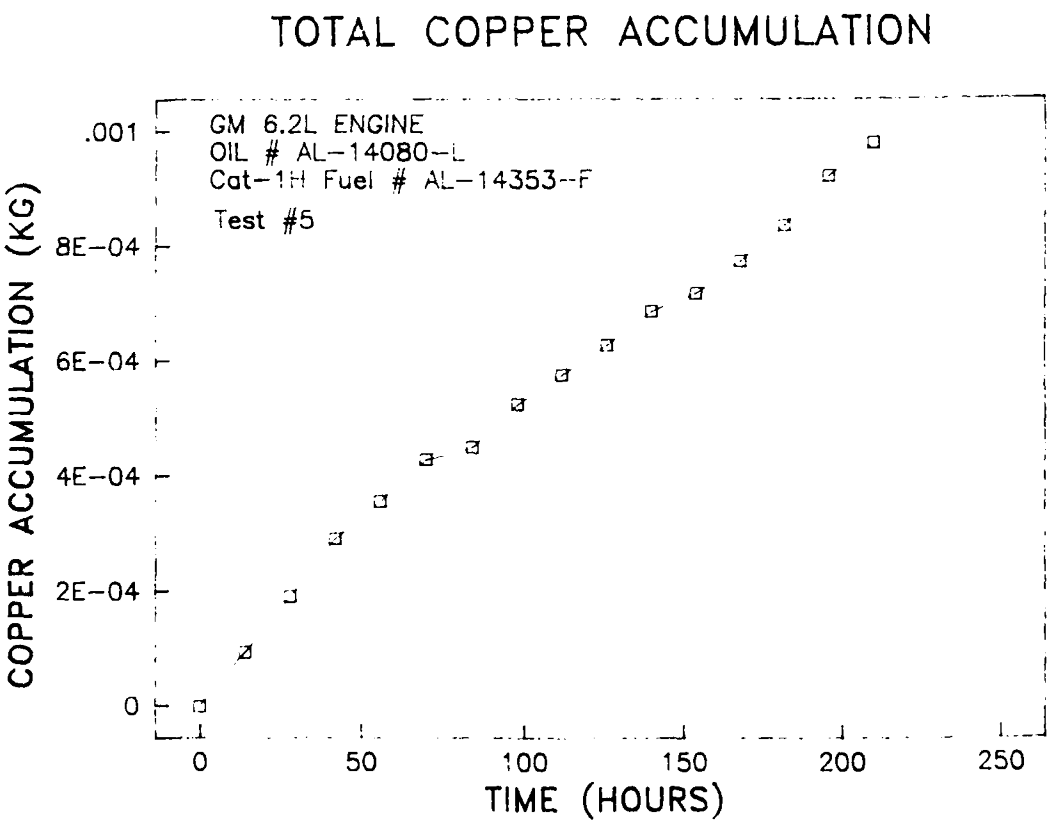


TOTAL OIL CONSUMPTION



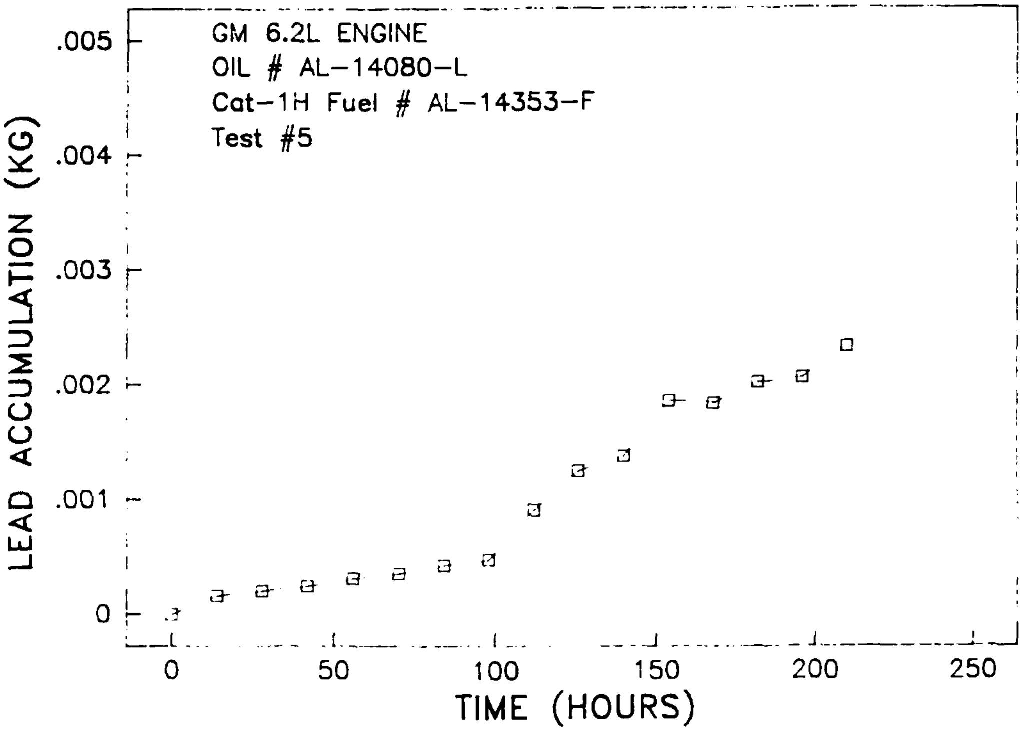


TOTAL IRON ACCUMULATION
GM 6.2L Engine
OIL # AL-14080-L
Cat-1H Fuel # AL-14353-F
Test #5
IRON ACCUMULATION (KG)
.01
.008
.006
.004
.002
0
0
50
100
150
200
250
TIME (HOURS)

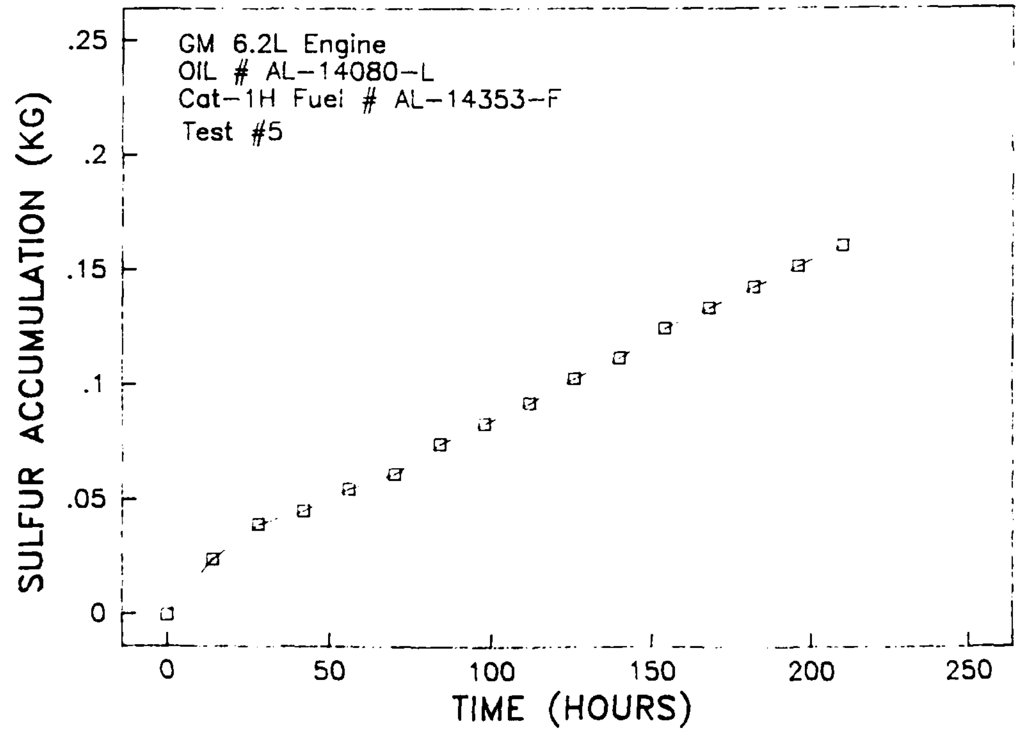


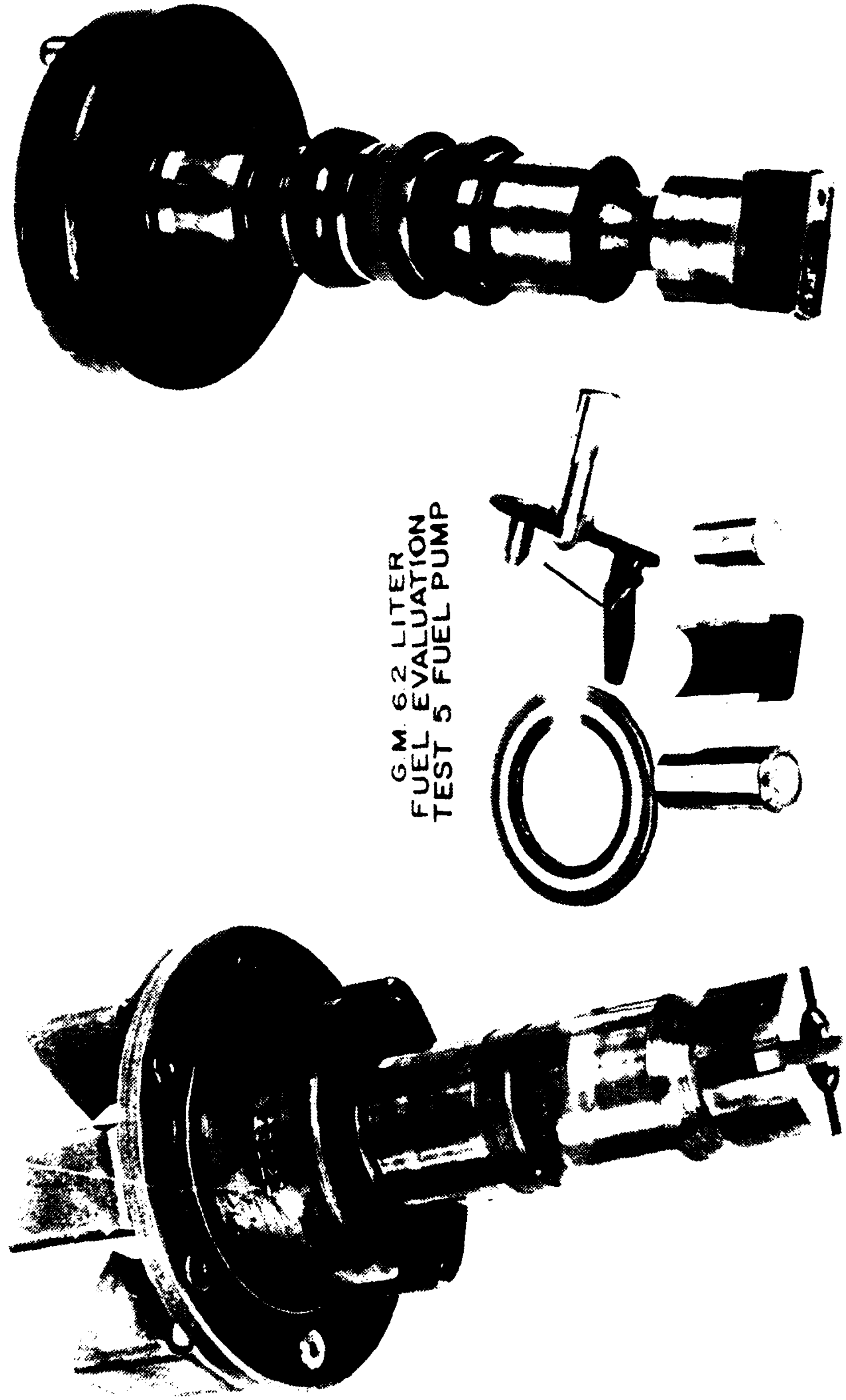
TOTAL COPPER ACCUMULATION
GM 6.2L ENGINE
OIL # AL-14080-L
Cat-1H Fuel # AL-14353-F
Test #5
COPPER ACCUMULATION (KG)
.001
8E-04
6E-04
4E-04
2E-04
0
0
50
100
150
200
250
TIME (HOURS)

TOTAL LEAD ACCUMULATION

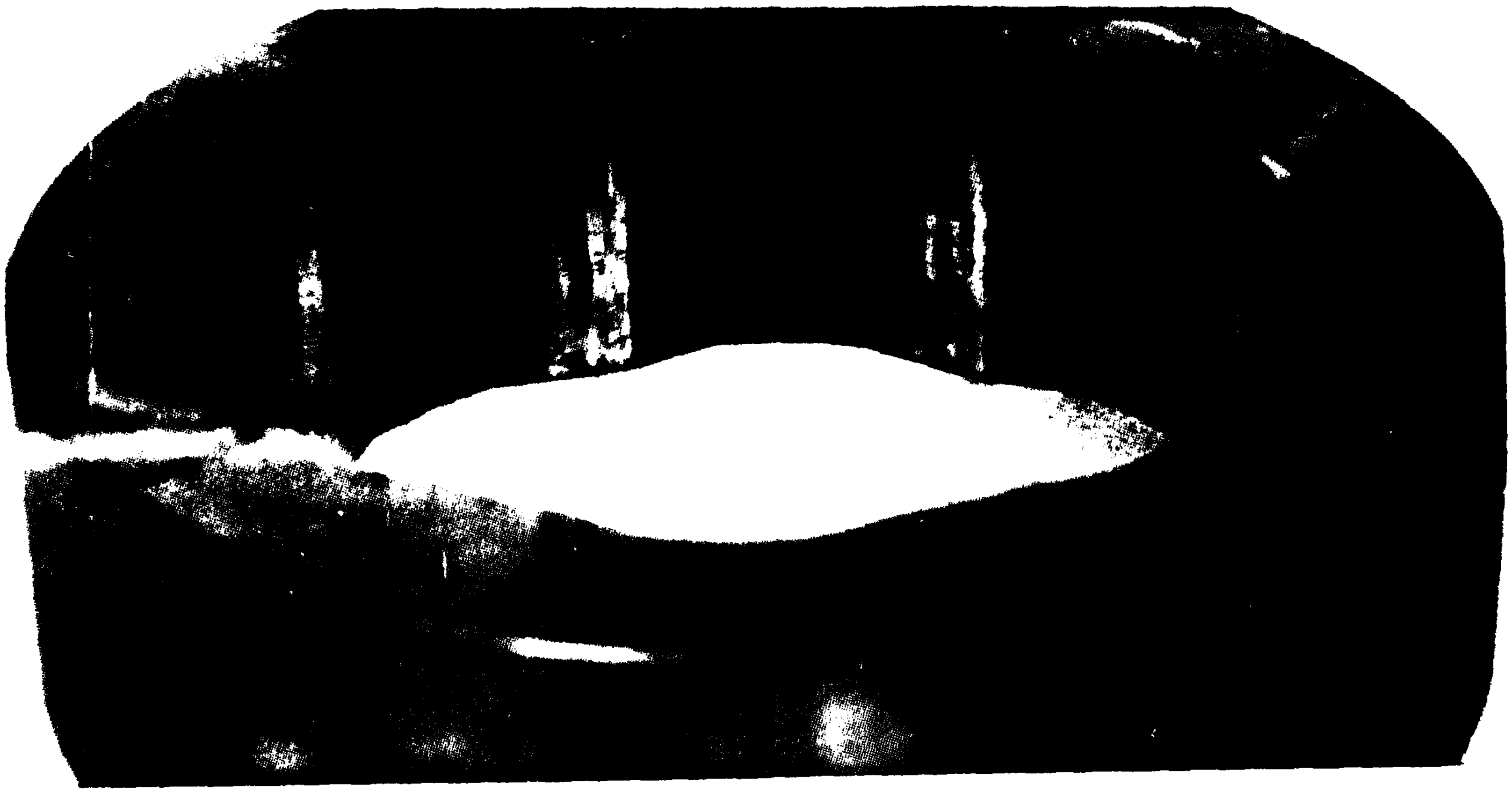


TOTAL SULFUR ACCUMULATION

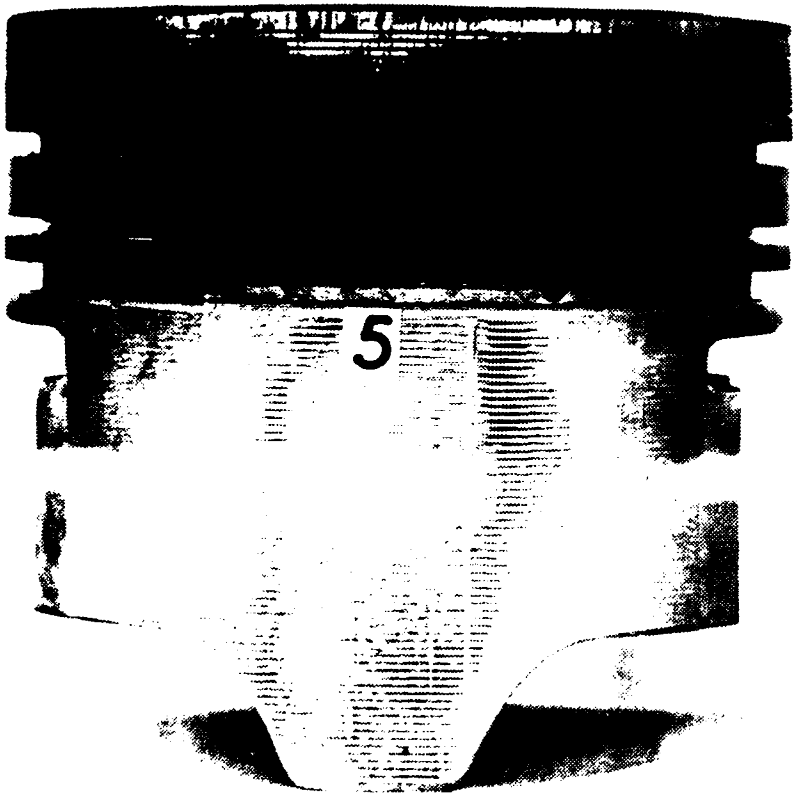



G.M. 6.2 LITER
FUEL EVALUATION
TEST 5 FUEL PUMP

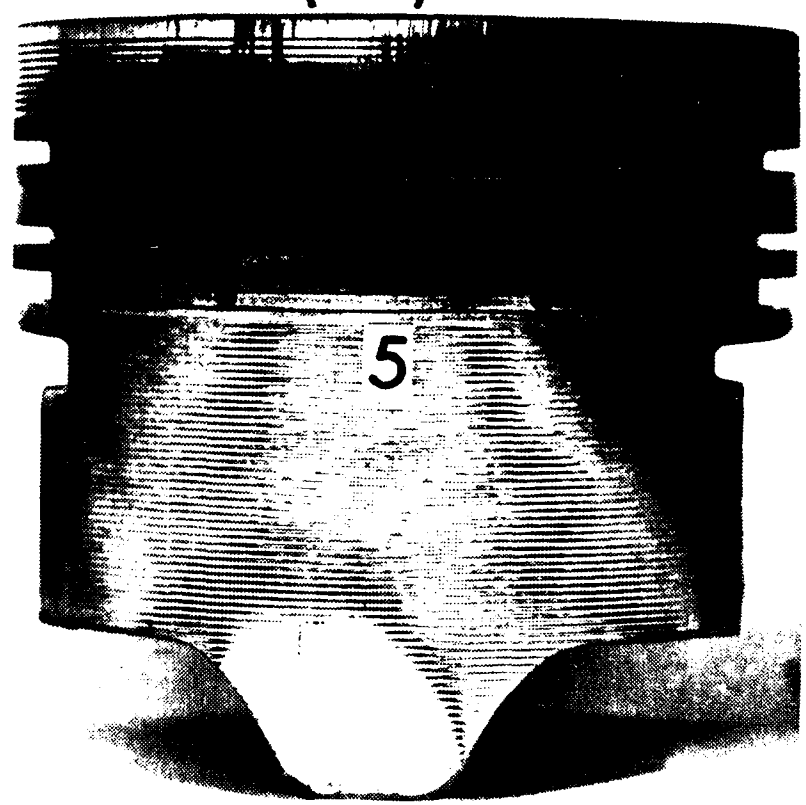
G.M. 6.2 LITER
FUEL EVALUATION
TEST 5 FUEL PUMP



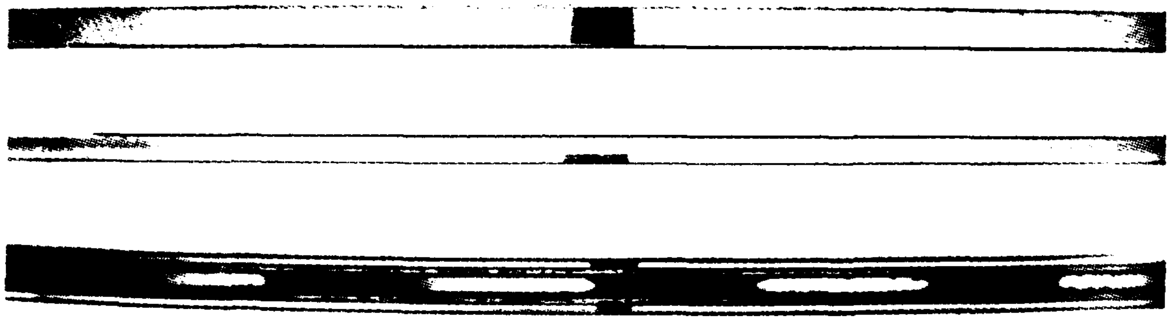
G.M. 6.2 LITER TEST #5
FUEL EVALUATION
(T)

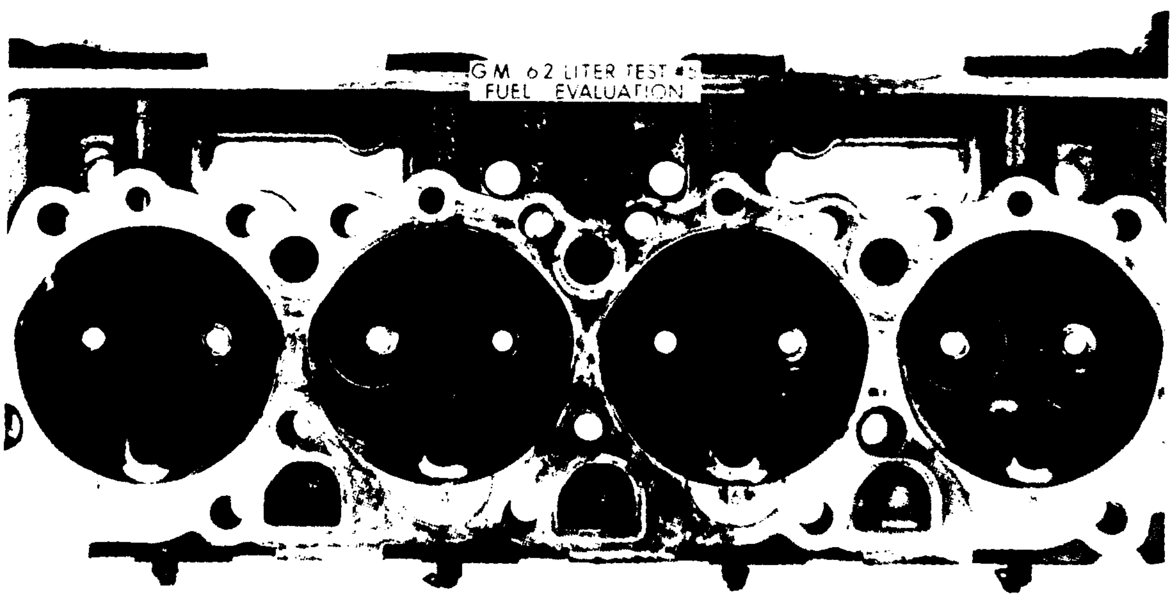


G.M. 6.2 LITER TEST #5
FUEL EVALUATION
(AT)

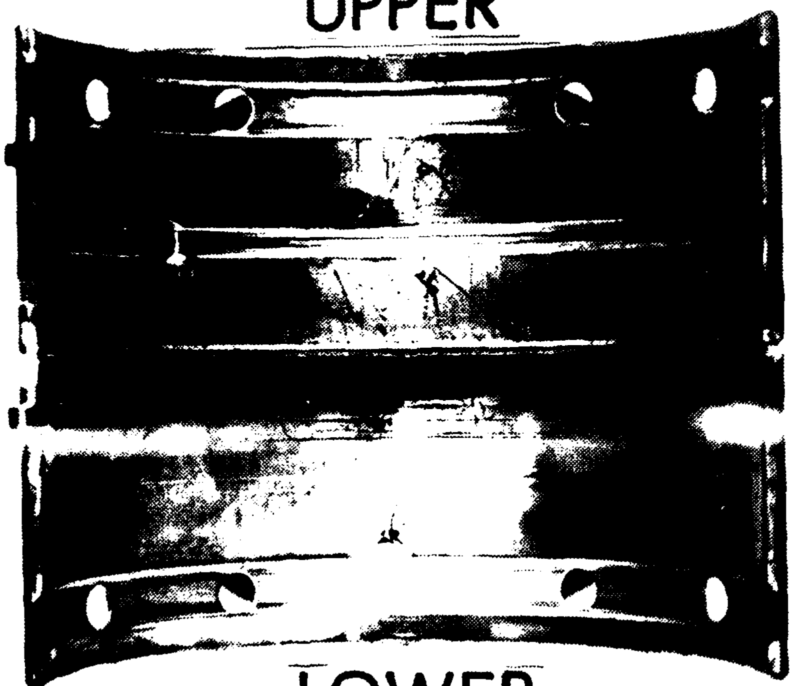


G.M. 6.2 LITER TEST #5
FUEL EVALUATION
5





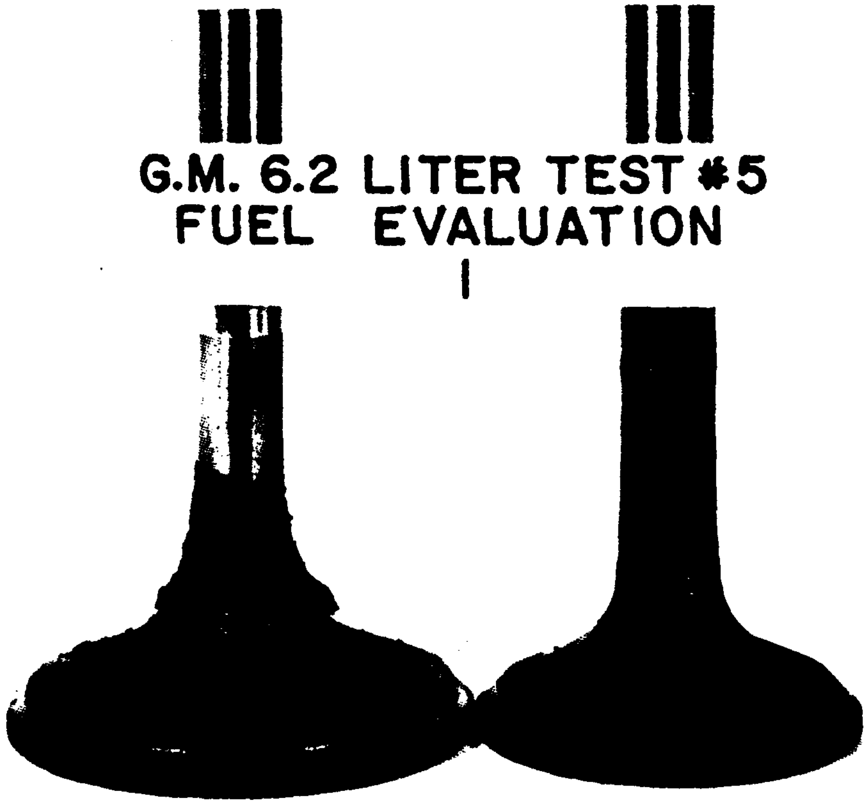
G.M. 6.2 LITER TEST # 5
FUEL EVALUATION
MAIN BEARINGS
UPPER

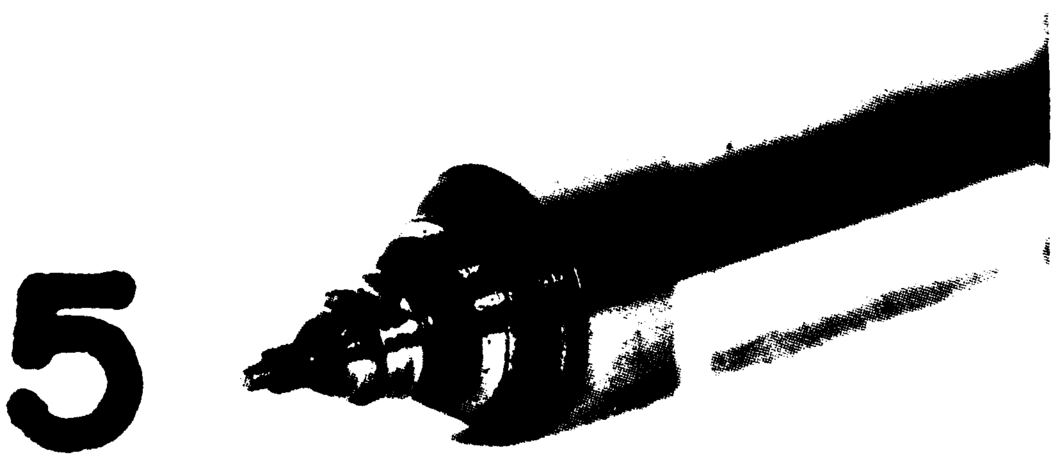


LOWER
5

G.M. 6.2 LITER TEST # 5
FUEL EVALUATION
ROD BEARINGS
UPPER

LOWER
4


G.M. 6.2 LITER TEST #5
FUEL EVALUATION
1


5

APPENDIX C
Test Data

GM 6.2L Engine
210-Hour Test
JP-8 Fuel

GM 6.2 l
JP-8
ENGINE MEASUREMENTS
SERIAL NUMBER: DJB 1003

Cylinder Bore	Minimum	Maximum	Average	Specified Limits
Diameter	3.9777	3.9786	3.9782	3.9759 - 3.9789
Out of Round	0.0000	0.0007	0.0003	—— 0.0008
Taper-Thrust	0.0001	0.0005	0.0004	—— 0.0008
Piston Clearances				
Bores 1-6	0.0040	0.0050	0.0044	0.0035 - 0.0045
Bores 7-8	0.0055	0.0046	0.0051	0.0040 - 0.0050
Piston Rings				
Groove Clearance				
2nd	0.0015	0.0020	0.0018	0.0015 - 0.0030
Oil	0.0015	0.0020	0.0018	0.0016 - 0.0038
End Gap				
Top	0.0250	0.0280	0.0270	0.0120 - 0.0220
2nd	0.0500	0.0420	0.0450	0.0290 - 0.0390
Oil	0.0250	0.0270	0.0260	0.0100 - 0.0200
Piston Pin				
Diameter	1.2208	1.2210	1.2209	1.2203 - 1.2206
Clearance	0.0001	0.0012	0.0005	0.0004 - 0.0006
Fit in Rod	0.0008	0.0014	0.0011	0.0003 - 0.0012
Camshaft				
Diameter				
Bearing 1-4	2.1655	2.1660	2.1657	2.1644 - 2.1663
Bearing 5	——	——	2.0083	2.0069 - 2.0088
Clearance	0.0027	0.0034	0.0030	0.0015 - 0.0044
Crankshaft				
Journal Diameter				
1-4	2.9500	2.9502	2.9501	2.9495 - 2.9504
5	——	——	2.9499	2.9493 - 2.9502
Out of Round	0.0000	0.0002	0.0000	0.0002
Clearance				
1-4	0.0040	0.0038	0.0042	0.0018 - 0.0033
5			0.0038	0.0022 - 0.0037
Crankpin				
Diameter	2.3984	2.3987	2.3986	2.3981 - 2.3992
Out of Round	0.0000	0.0002	0.0000	0.0002
Clearance	0.0033	0.0035	0.0035	0.0018 - 0.0039
Valve				
Stem Clearance				
Intake	0.0019	0.0026	0.0022	0.0010 - 0.0027
Exhaust	0.0023	0.0030	0.0028	0.0010 - 0.0027

NOTE: Measurements are in inches.

PROPERTIES OF JP-8 OBTAINED FROM SUNTECH

PROPERTY	METHOD	REQUIREMENTS OF NATO F-34	AL-14216-F
Color	D 156	(a)	+15(Saybolt)
Total Acid Number, mg KOH/g	D 3242	0.015 max	0.005
Aromatics, vol%	D 1319	25.0 max	19.0
Olefins, vol%	D 1319	5.0 max	0
Sulfur, total wt % (XRF)	D 2622	0.3	<0.01
Mercaptan sulfur, wt%	D 3227	0.001max	0.0002
Distillation, GC, *C	D 2887		
Initial boiling point		(a)	136.2
10 % recovered		186 max	169.3
20 % recovered		(a)	180.6
50 % recovered		(a)	205.6
90 % recovered		(a)	236.9
End point		330 max	262.6
Flash Point, *C	D 93	38 min	56
Gravity, *API	D 1298	37 - 51	40.3
Density, kg/L at 15*C	D 1298	0.775 - 0.840	0.8232
Freezing point, *C	D 2386	-50 max	-55
Kin viscosity at -20*C, cSt	D 445	8.0 max	4.14
Net heat of combustion,MJ/kg(Btu/lb)		42.8(18,400) min	43.106 (18,532)
Hydrogen content, wt %		13.5 min	13.69
Smoke point, mm	D 1322	19 min	22.2
Copper corrosion, 2hr @ 100*C	D 130	1B max	1A
Thermal stability (JFTOT),Code	D 3241	<3	1
Change in pressure drop, mm Hg		25 max	0
Existent gum, mg/100mL	D 381	7.0 max	0.2
Particulate matter, mg/L	D 2276	1.0 max	1.1 (b)
Water reaction, interface rating	D 1094	1b	1b
Water separation index, modified	D 2550	70 max	
Fuel system icing inhibitor		0.10 - 0.15	0.01,0.04
Fuel electrical conductvty, pS/m	D 2624	200-600	170,90
Filtration time, minutes	Apdx A MIL-T-5624	15 max	72
Cetane Number		NR(c)	41
BOCLE, scar diameter, mm		NR	0.34

(a) Report
(b) _Outside of specification limits.
(c) No requirement.

GM 6.2 l ENGINE
OPERATING CONDITIONS SUMMARY
LUBRICANT: AL-14080-L
JP-8 FUEL: AL-14216-F

	Full Power Mode (3600 RPM)		Idle Mode (800 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed (rpm)	3600	0.745	779	28.60
Torque (ft-lb)	186.3	22.30	8.41	1.64
Fuel Consumption (lb/hr)	74.1	3.18	5.44	1.02
Observed Power (Bhp)	127.7	15.3	1.25	0.264
BSFC (lb/Bhp-hr)	0.589	0.0720	4.41	0.687
Oil Gallery Pressure (psi)	52.9	1.99	56.5	1.44
Temperatures (°F)				
Water Jacket Inlet	161.8	1.03	93.5	3.77
Water Jacket Outlet	177.9	0.929	101.1	3.76
Oil Sump	233.4	6.82	121.8	5.71
Fuel Inlet	105.0	4.34	91.8	3.86
Air Inlet	95.4	7.11	87.9	4.90
Exhaust Temperatures (°F)				
Cylinder 1	1353	57.9	206.4	48.9
Cylinder 2	1285	43.6	225.7	38.5
Cylinder 3	1407	66.7	212.1	30.3
Cylinder 4	1313	61.7	210.4	41.0
Cylinder 5	1410	61.2	209.7	32.5
Cylinder 6	1325	52.0	202.8	34.6
Cylinder 7	1290	50.0	168.9	54.0
Cylinder 8	1328	51.2	230.7	41.1
Common	1107	56.6	158.0	20.7

GM 6.2 I
JP-8
WEAR MEASUREMENTS

Cylinder Bore Diameter Change

	1 T-AT	1 F-B	3 T-AT	3 F-B	5 T-AT	5 F-B	7 T-AT	7 F-B
Top	0.0004	0.0002	0.0002	0.0002	0.0003	0.0001	0.0003	0.0002
Middle	0.0003	0.0002	0.0003	0.0001	0.0002	0.0001	0.0003	0.0001
Bottom	0.0004	0.0002	0.0004	0.0001	0.0003	0.0000	0.0003	0.0004

	2 T-AT	2 F-B	4 T-AT	4 F-B	6 T-AT	6 F-B	8 T-AT	8 F-B
Top	0.0005	0.0001	0.0003	0.0002	0.0003	0.0001	0.0004	0.0001
Middle	0.0004	0.0000	0.0003	0.0000	0.0007	0.0000	0.0003	0.0000
Bottom	0.0004	0.0001	0.0004	0.0000	0.0003	-0.0001	0.0003	0.0000

Average Change

	T-AT	F-B
Top	0.0003	0.0002
Middle	0.0003	0.0001
Bottom	0.0004	0.0001

Overall Average Change: 0.0002

	Cylinder 1	2	3	4	5	6	7	8	AVG
Piston Ring End Gap Change									
Rings									
Top	0.007	0.006	0.008	0.005	0.007	0.006	0.007	0.006	0.007
2nd	0.001	0.001	0.002	0.001	-0.005	0.003	0.003	0.003	0.001
Oil	0.003	0.001	0.003	0.004	-0.006	0.004	0.004	0.004	0.002

Overall Average Change: 0.003

Bearing Weight Change

	1	2	3	4	5	6	7	8	AVG
Main									
Upper	0.0413	0.0335	0.0248	0.0336	0.0537				0.0374
Lower	0.0417	0.0463	0.0687	0.0426	0.0824				0.0563

Overall Average Change: 0.0469

	1	2	3	4	5	6	7	8	AVG
Rod Bearing									
Upper	0.1308	0.0888	0.1008	0.0370	0.0883	0.0838	0.0791	0.0801	0.0861
Lower	0.0290	0.4310	0.0253	0.0383	0.0239	0.0345	0.0222	0.0235	0.0810

Overall Average Change: 0.0835 grams

Valve Recession

	1	2	3	4	5	6	7	8	AVG
Intake	-0.0021	0.0002	-0.0009	0.0005	0.0000	0.0018	-0.0006	-0.0010	-0.0003
Exhaust	-0.0074	0.0005	-0.0003	-0.0010	-0.0020	-0.0012	-0.0021	-0.0007	-0.0018

Overall Average Change: -0.0011

NOTE: Measurements are in inches.

GM 6.2 1
JP-8
POST TEST ENGINE CONDITION AND DEPOSITS

	Cylinder Number								
	1	2	3	4	5	6	7	8	AVG
Cylinder Liner									
Liner Scuffing, % Area									
Thrust					0.0				0.00
Anti-Thrust					0.0				0.00
% Total Area					0.0				0.00
								Overall:	0.00
Liner Polished, % Area									
Thrust					0.0				0.00
Anti-Thrust					0.0				0.00
% Total Area					0.0				0.00
								Overall:	0.00
Pistons									
Ring Face Distress (Demerits)									
Top	25.00	5.00	2.50	16.25	16.25	1.25	1.25	20.00	10.94
2nd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
								Overall:	5.47
Piston Skirt Rating									
Thrust					N*				
Anti-Thrust					N				
Piston WTD Rating	183.625	119.625	131.750	130.625	133.250	137.750	158.625	147.750	142.875
Exhaust Valves									
Deposits									
Head					1/4 ASC**				
Face					1/4 AHC**				
Tulip	0.50	0.25	0.10	0.20	0.10	0.10	0.75	1.0	
Steam					#9				
Surface Conditions									
Freeness in Guide					F*				
Head					N				
Face					N				
Seat					N				
Stem					N				
Tip					N				
Other Ratings									
Prechamber Deposits (grams)	0.7545	0.2177	0.1799	0.2637	0.1611	0.1564	0.2366	0.1191	
Bearing Surface					No Abnormalities				

* N - normal, F - free
** 1/4 ASC, 1/4 AHC lightest coating possible of soft carbon and hard carbon respectively.

GM 6.2 1
JP-8
FUEL INJECTOR TEST

	Cylinder Number								
	1	2	3	4	5	6	7	8	AVG
(Set 1 replaced at 32 hours.)									
Pop-Off Pressure (psi)									
Before Test	1800	2050	1800	1800	1900	1900	1800	1800	1856
After Test	1650	1850	1600	1650	5000	1700	1650	1600	1671
Overall Average Excluding #5 (After Test): 185 psi									
Report									
Before Test	Good	Weak	None	Good	Fair	Good	Good	Good	
After Test	None	Good	None	Fair	Seized	Poor	None	Poor	
(Set 2 installed at 32 hours and replaced at 97 hours.)									
Pop-Off Pressure (psi)									
Before Test (CAT 1 H)	1800	2000	1900	1850	1800	1850	1800	1800	1850
After Test (CAT 1 H)	1600	1700	1700	1800	2200	1650	1650	1550	1731
After Test (JP-8)	1600	1700	1700	1700	1700	1700	1700	1650	1681
Overall Change: 119 psi									
Report									
Before Test	Weak	Poor	Good	Good	Fair	Poor	Fair	Fair	
After Test	None	None	Good	Weak	Weak	None	None	None	
After Test (JP-8)	None	Good	Good	Good	Good	Good	Good	Good	
(Set 3 installed at 97 hours and made end of test.)									
Pop-Off Pressure (psi)									
Before Test	1750	1850	1800	1800	1800	1800	1950	1800	1819
After Test	1700	1800	1700	1550	1600	1550	1650	1600	1644
Overall Change: 175 psi									
Report									
Before Test	Good	Weak	Good	Good	Good	Weak	Good	Good	
After Test	Good	Weak	Good	None	Fair	None	Fair	Fair	
Needle Scuffing									
Demerits	0.0	0.0	0.30	0.70	0.25	0.0	0.70	0.60	0.95

GM 6.2 1
JP-8
PUMP TESTS

(Initial Pump Removed at 168 Hours)

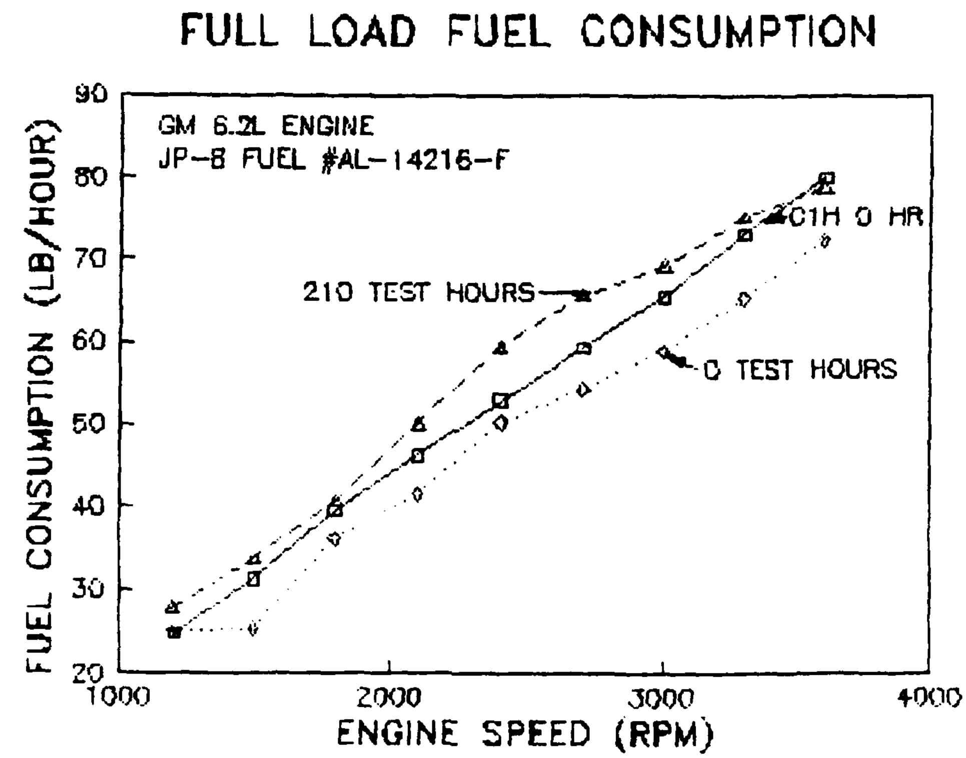
	Cylinder Number								
	1	2	3	4	5	6	7	8	AVG
Fuel Pump Calibration (ml/min)									
Before Test @ 1000 rpm	49.4	51.1	49.6	50.1	49.1	48.6	50.1	48.6	49.6
After Test @ 1000 rpm*	54.3	56.8	54.2	50.5	53.4	48.0	54.5	55.0	53.3
					Overall: 3.7				
After Test @ 1800 rpm*	84.2	103.1	101.9	111.4	98.4	92.5	87.8	98.4	97.2

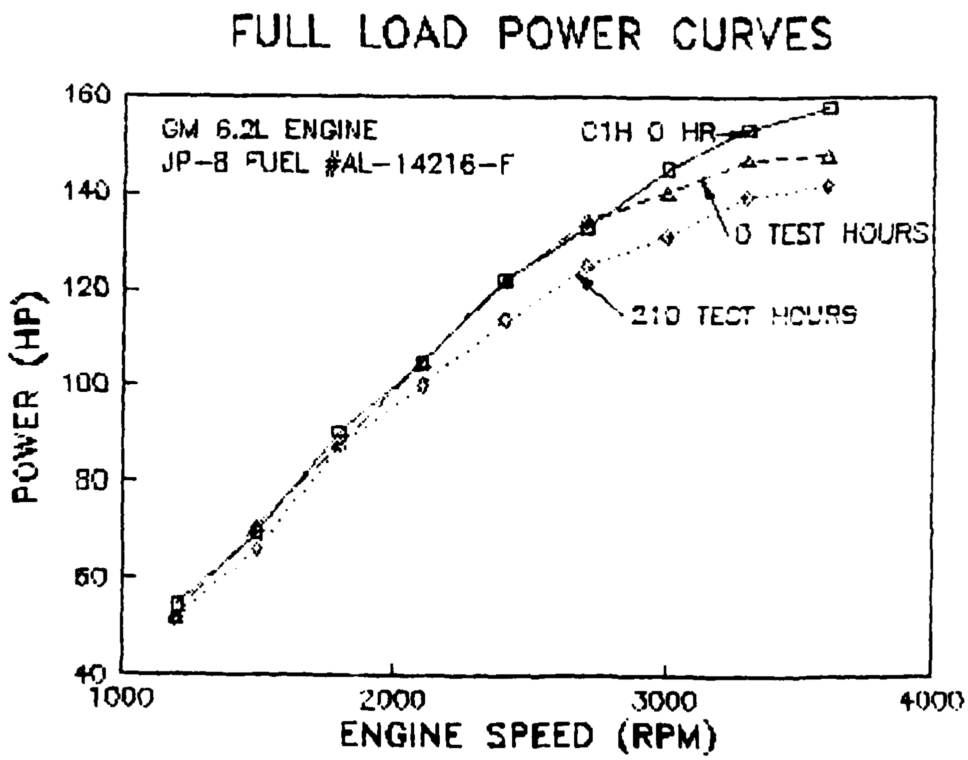
(Pump Installed @ 168 Hours Made End of Test)

	1	2	3	4	5	6	7	8	AVG
Fuel Pump Calibration (ml/min)									
Before Test @ 1800 rpm	82.8	90.6	89.2	86.5	86.5	83.7	81.9	88.3	86.2
After Test @ 1800 rpm	103.6	110.9	115.8	118.3	108.5	104.9	108.5	109.7	110.0
After Test @ 1000 rpm	64.1	62.1	62.1	64.1	62.1	60.1	60.1	60.8	61.9

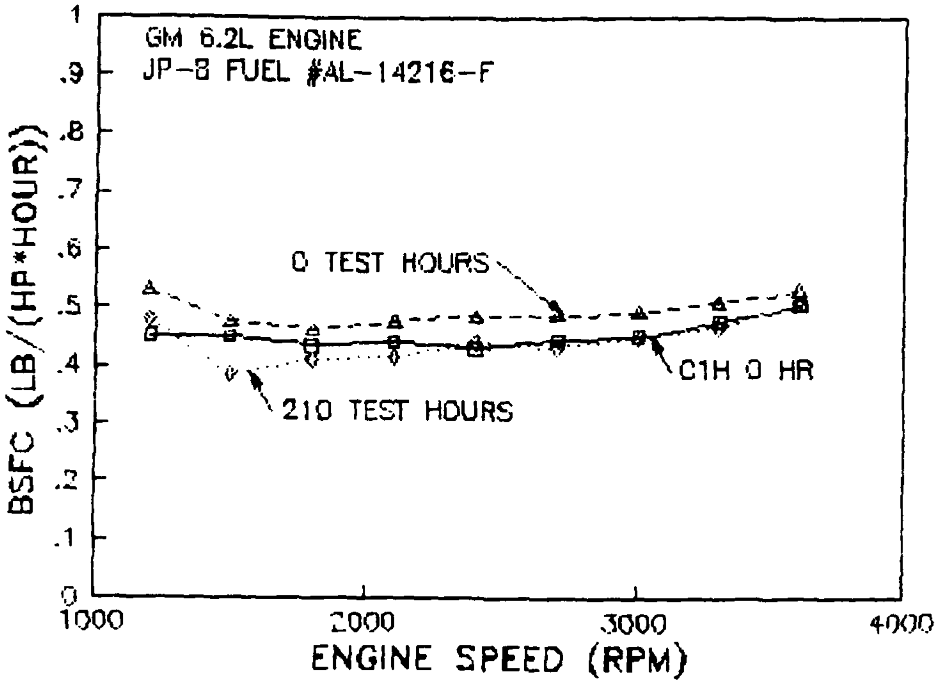
Overall Change @ 1800 rpm: 23.8

* Pump reported to make "intermediate noises, like rotor hanging up".

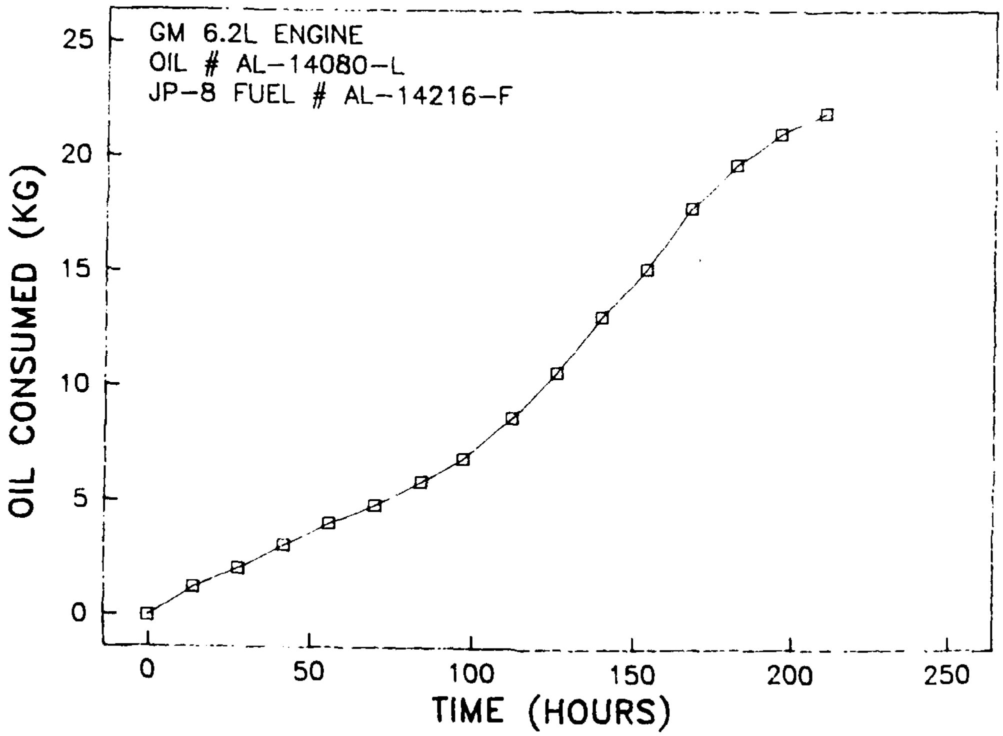

FULL LOAD FUEL CONSUMPTION
GM 6.2L ENGINE
JP-8 FUEL #AL-14216-F
C1H 0 HR
210 TEST HOURS
0 TEST HOURS
FUEL CONSUMPTION (LB/HOUR)
ENGINE SPEED (RPM)
90
80
70
60
50
40
30
20
1000
2000
3000
4000

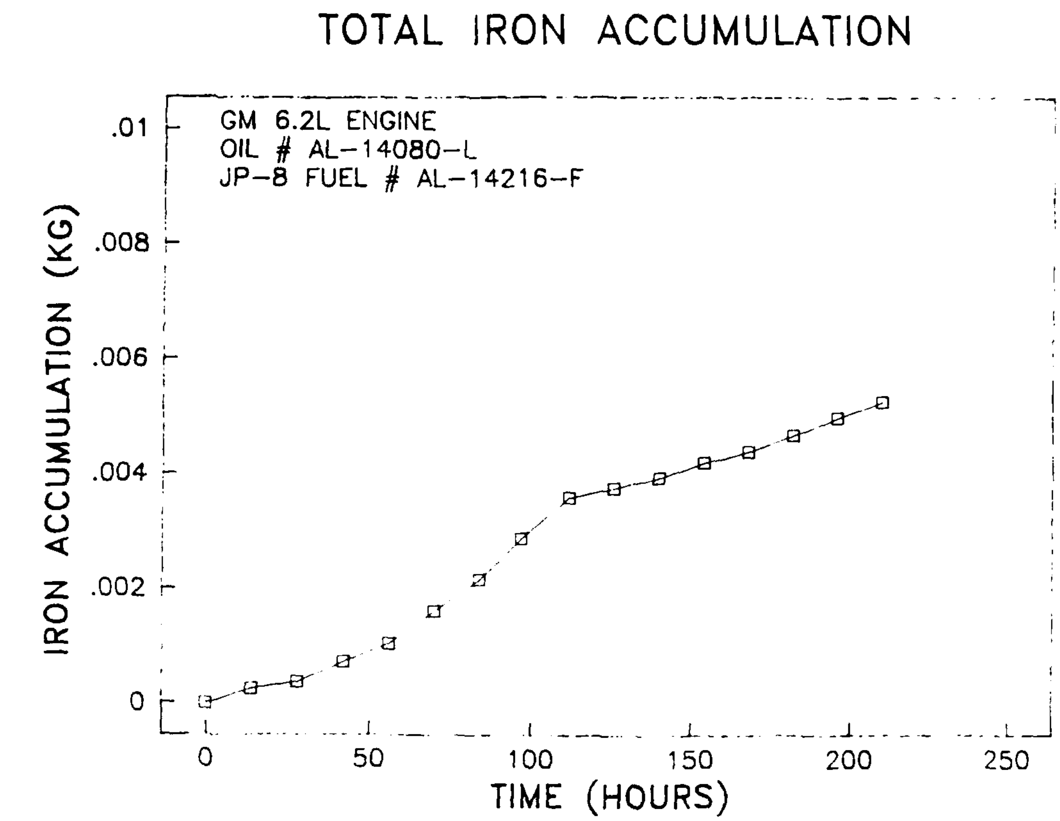

FULL LOAD POWER CURVES
GM 6.2L ENGINE
JP-8 FUEL #AL-14216-F
C1H 0 HR
0 TEST HOURS
210 TEST HOURS
POWER (HP)
ENGINE SPEED (RPM)
160
140
120
100
80
60
40
1000
2000
3000
4000

FULL LOAD BSFC CURVES

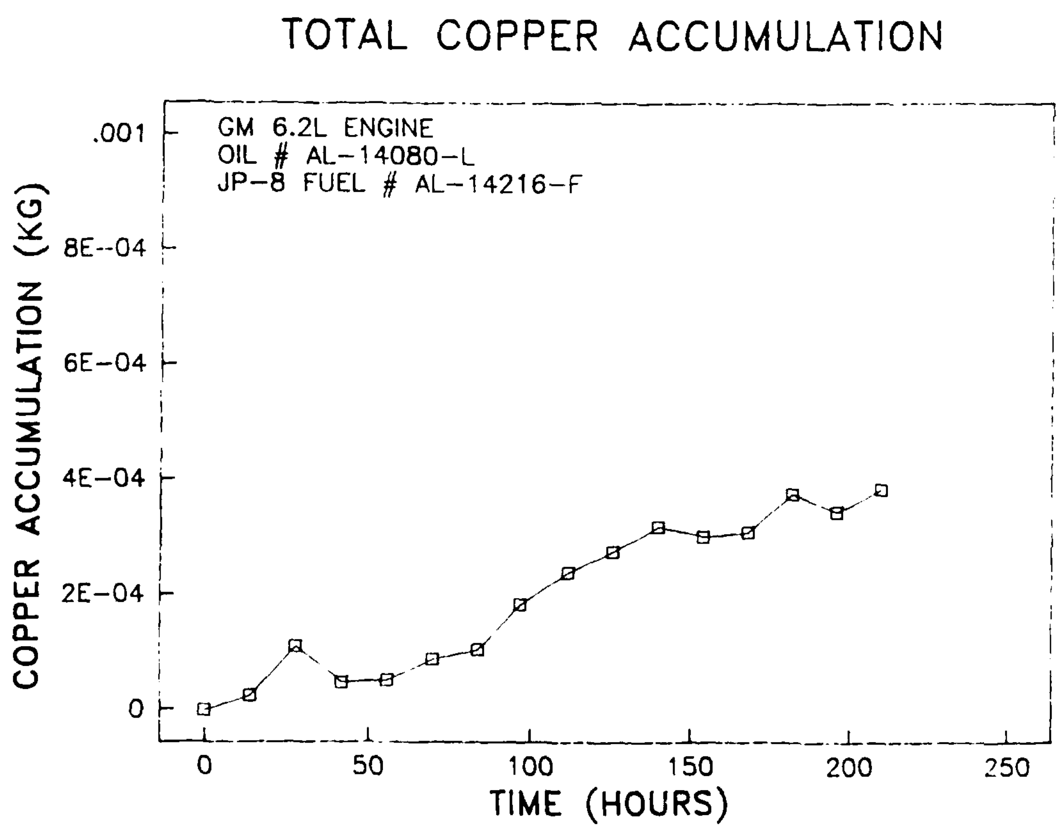


TOTAL OIL CONSUMPTION



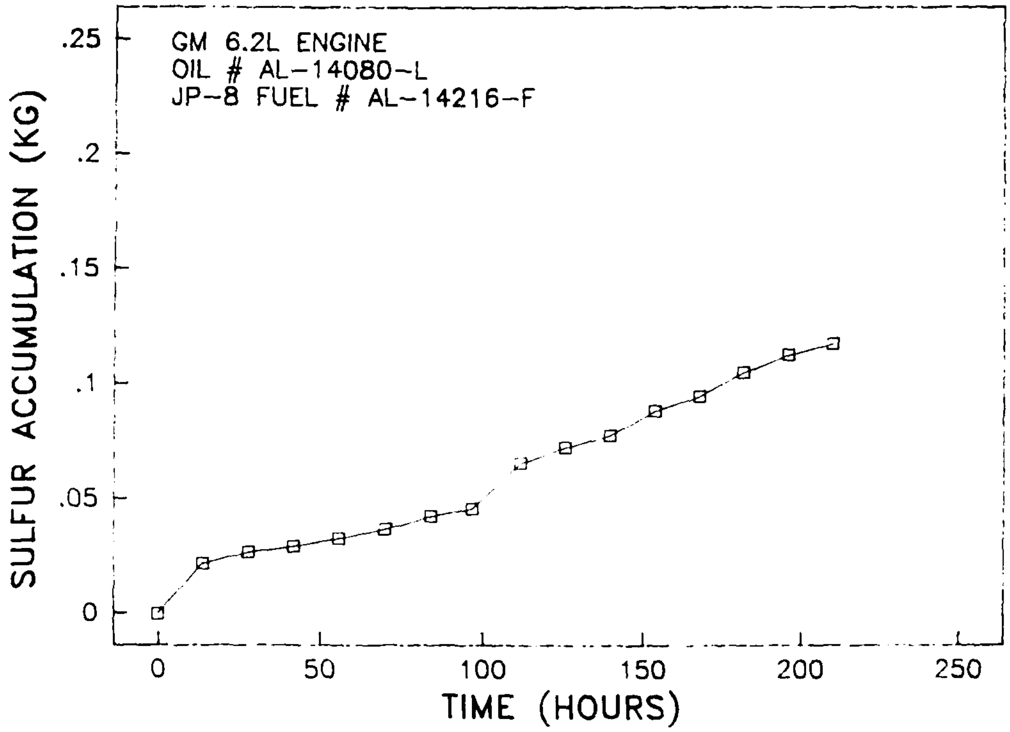


TOTAL IRON ACCUMULATION
GM 6.2L ENGINE
OIL # AL-14080-L
JP-8 FUEL # AL-14216-F
IRON ACCUMULATION (KG)
.01
.008
.006
.004
.002
0
0
50
100
150
200
250
TIME (HOURS)



TOTAL COPPER ACCUMULATION
GM 6.2L ENGINE
OIL # AL-14080-L
JP-8 FUEL # AL-14216-F
COPPER ACCUMULATION (KG)
.001
8E--04
6E-04
4E-04
2E-04
0
0
50
100
150
200
250
TIME (HOURS)

TOTAL SULFUR ACCUMULATION



APPENDIX D

Test Data and Photographs

GM 6.2L Engine

400-Hour NATO Test Cycle

JP-8 Fuel

GM 6.2L
JP-8
ENGINE MEASUREMENTS
SERIAL NUMBER: DJB-1003

	Minimum	Maximum	Average	Specified Limits
Cylinder Bore				
Diameter	3.9772	3.9789	3.9780	3.9759 - 3.9789
Out of Round	0.0002	0.0011	0.0005	— 0.0008
Taper-Thrust	0.0002	0.0007	0.0004	— 0.0008
Piston Clearances				
Bores 1-6	0.0026	0.0048	0.0034	0.0035 - 0.0045
Bores 7-8	0.0030	0.0043	0.0037	0.0040 - 0.0050
Piston Rings				
Groove Clearance				
2nd	0.0025	0.0025	0.0025	0.0015 - 0.0030
Oil	0.0015	0.0025	0.0023	0.0016 - 0.0038
End Gap				
Top	0.028	0.032	0.031	0.012 - 0.022
2nd	0.047	0.049	0.048	0.029 - 0.039
Oil	0.024	0.033	0.029	0.010 - 0.020
Piston Pin				
Diameter	1.2208	1.2208	1.2208	1.2203 - 1.2206
Clearance	0.0002	0.0005	0.0004	0.0004 - 0.0006
Fit in Rod	0.0009	0.0014	0.0011	0.0003 - 0.0012
Camshaft				
Diameters				
Bearings 1-4	2.1655	2.1658	2.1656	2.1644 - 2.1663
Bearing 5	2.0083	2.0083	2.0083	2.0069 - 2.0088
Clearance	0.0022	0.0033	0.0027	0.0015 - 0.0044
Crankshaft				
Journal				
Diameter 1-4	2.9500	2.9501	2.9500	2.9495 - 2.9504
Diameter 5	2.9497	2.9499	2.9498	2.9493 - 2.9502
Out of Round	0.0000	0.0002	0.0001	— 0.0002
Clearance 1-4	0.0034	0.0042	0.0037	0.0018 - 0.0033
Clearance 5	0.0039	0.0042	0.0041	0.0022 - 0.0037
Crankpin				
Diameter	2.3983	2.3986	2.3985	2.3981 - 2.3992
Out of Round	0.0000	0.0002	0.0001	— 0.0002
Clearance	0.0034	0.0044	0.0038	0.0018 - 0.0039
Valve				
Stem Clearance				
Intake	0.0019	0.0027	0.0023	0.001 - 0.0027
Exhaust	0.0027	0.0028	0.0027	0.001 - 0.0027

NOTE: Measurements are in inches.

PROPERTIES OF JP-8 OBTAINED FROM SUNTECH

PROPERTY	METHOD	REQUIREMENTS OF NATO F-34	AL-14216-F
Color	D 156	(a)	+15(Saybolt)
Total Acid Number, mg KOH/g	D 3242	0.015 max	0.005
Aromatics, vol%	D 1319	25.0 max	19.0
Olefins, vol%	D 1319	5.0 max	0
Sulfur, total wt % (XRF)	D 2622	0.3	<0.01
Mercaptan sulfur, wt%	D 3227	0.001max	0.0002
Distillation, GC, *C	D 2887		
Initial boiling point		(a)	136.2
10 % recovered		186 max	169.3
20 % recovered		(a)	180.6
50 % recovered		(a)	205.6
90 % recovered		(a)	236.9
End point		330 max	262.6
Flash Point, *C	D 93	38 min	56
Gravity, *API	D 1298	37 - 51	40.3
Density, kg/L at 15*C	D 1298	0.775 - 0.840	0.8232
Freezing point, *C	D 2386	-50 max	-55
Kin viscosity at -20*C, cSt	D 445	8.0 max	4.14
Net heat of combustion,MJ/kg(Btu/lb)		42.8(18,400) min	43.106 (18,532)
Hydrogen content, wt %		13.5 min	13.69
Smoke point, mm	D 1322	19 min	22.2
Copper corrosion, 2hr @ 100*C	D 130	1B max	1A
Thermal stability (JFTOT),Code	D 3241	<3	1
Change in pressure drop, mm Hg		25 max	0
Existent gum, mg/100mL	D 381	7.0 max	0.2
Particulate matter, mg/L	D 2276	1.0 max	1.1 (b)
Water reaction, interface rating	D 1094	1b	1b
Water separation index, modified	D 2550	70 max	
Fuel system icing inhibitor		0.10 - 0.15	0.01,0.04
Fuel electrical conductvty, pS/m	D 2624	200-600	170,90
Filtration time, minutes	Apdx A MIL-T-5624	15 max	72
Cetane Number		NR(c)	41
BOCLE, scar diameter, mm		NR	0.34

(a) Report
(b) Outside of specification limits.
(c) No requirement.

GM 6.2L ENGINE

Operating Conditions Summary
Lubricant: AL-14080-L
JP-8 Fuel: AL-14216-F
(400-Hour NATO Test)

	3600 RPM		2000 RPM	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, RPM	3601.2	5.23	2000.9	4.22
Torque, ft-lb	178.7	5.65	209.6	7.60
Fuel Consumption, lb/hr	70.8	1.44	39.4	1.05
Observed Power, Bhp	122.5	3.94	79.8	2.95
BSFC, lb/Bhp-hr	0.578	0.015	0.493	0.015
Temperatures, °F				
Water In	190.9	1.33	189.9	0.94
Water Out	200.1	1.35	199.8	1.11
Oil Sump	250.3	3.33	208.9	3.11
Fuel In	82.9	6.59	79.0	6.25
Inlet Air	84.9	8.23	79.3	7.76
Exhaust Common	1254.4	22.01	1056.4	21.35
Pressures				
Oil, psi	41.79	0.93	45.25	2.12
Fuel Transfer, psi	4.57	0.22	5.76	0.14
Inlet Restriction, in H_2O	10.4	0.29	3.2	0.12
Exhaust Back Pressure, in Hg	1.2	0.06	0.25	0.06
Blowby, in H_2O	3.86	0.94	1.01	0.16
Ambient Conditions				
Barometer, in Hg	29.21	0.17	29.21	0.17
Relative Humidity	64.53	18.93	62.7	20.49

GM 6.2L
JP-8
WEAR METALS BY XRF
LUBRICANT: AL-14080-L

Test Time Hours	Wear Metals (ppm) Fe	Cu	Cr	Pb	S
20	53	29	*	*	0.43
40	68	33	*	*	0.42
60	109	50	*	*	0.46
80	128	11	*	*	0.46
100	160	20	*	*	0.47
120	80	11	8	*	0.49
140	89	16	*	*	0.48
160	113	*	*	*	0.49
180	124	10	*	*	0.48
200	143	10	*	*	0.47
220	89	25	*	*	0.48
240	102	*	*	*	0.47
260	97	*	*	*	0.48
280	119	22	*	*	0.48
300	136	*	*	*	0.48
320	54	*	*	*	0.46
340	73	*	*	*	0.45
360	90	*	*	*	0.46
380	78	*	*	*	0.47
400	111	*	*	*	0.46

* Below detectable limits.

GM 6.2L
JP-8
Lubricant: AL-14080L

	ASTM Method	Test Time, Hours 0	100	200	300	400
Kinematic Viscosity @ 40°C cSt	D445	97.13	210.16	232.24	249.35	278.82
Kinematic Viscosity @ 100°C cSt	D445	11.04	18.50	19.75	20.58	22.08
Total Acid Number mg KOH/g	D664	2.51	6.48	7.92	7.71	9.50
Total Base Number mg KOH/g	D664	6.49	2.93	2.49	2.59	2.31
Pentane B Insolubles wt %	D893	--	2.08	2.10	2.17	2.35
Toluene B Insolubles wt %	D893	--	1.89	1.91	1.97	2.22
Flash Point, °C	D92	230	249	257	257	246

GM 6.2 L
JP-8
FUEL INJECTOR AND PUMP TESTS
Engine Serial Number: DJ1003
Pump Serial Number: 4779193

	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg.
Pop-Off Pressure(psi)									
Before Test	1700	1700	1675	1675	1700	1650	1850	1675	1703
After Test	1650	1500	1700	1500	1500	1400	1500	1400	1519

Overall Decrease: 184 psi

Report	
Before Test	Yes
After Test	Yes

Fuel Pump Calibration

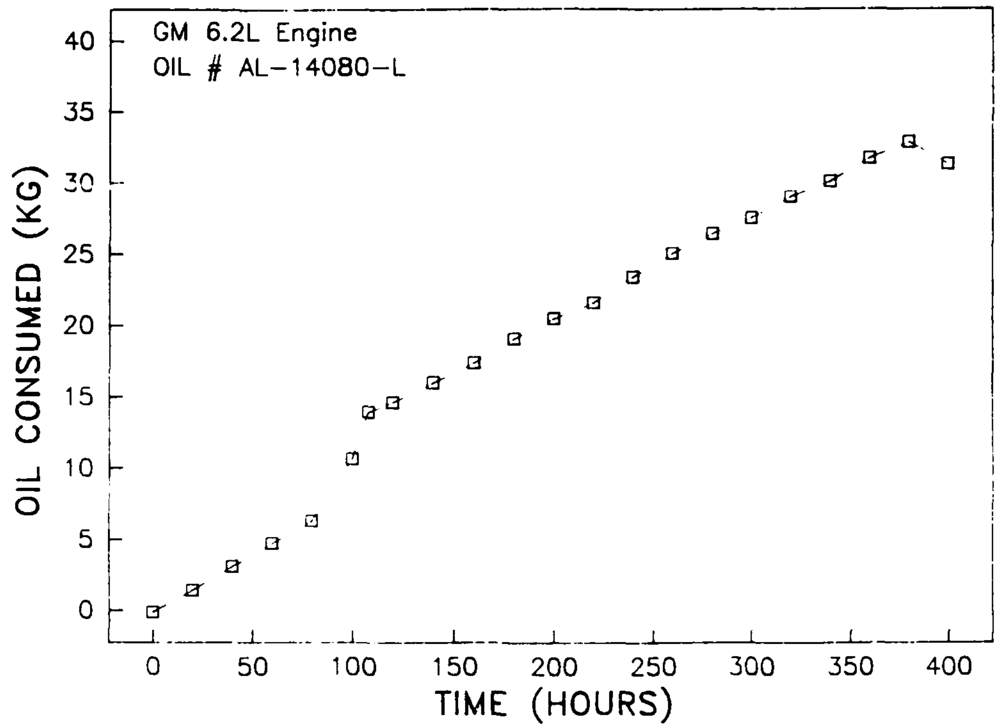
	1	2	3	4	5	6	7	8	Avg.
(ml/min) @ 1000 RPM									
Before Test	49.5	50.5	50.5	51.1	49.5	48.9	48.4	48.4	49.6
After Test	48.4	50.0	49.5	50.5	47.4	47.9	47.9	47.9	48.7

Overall Decrease: .9 ml/min

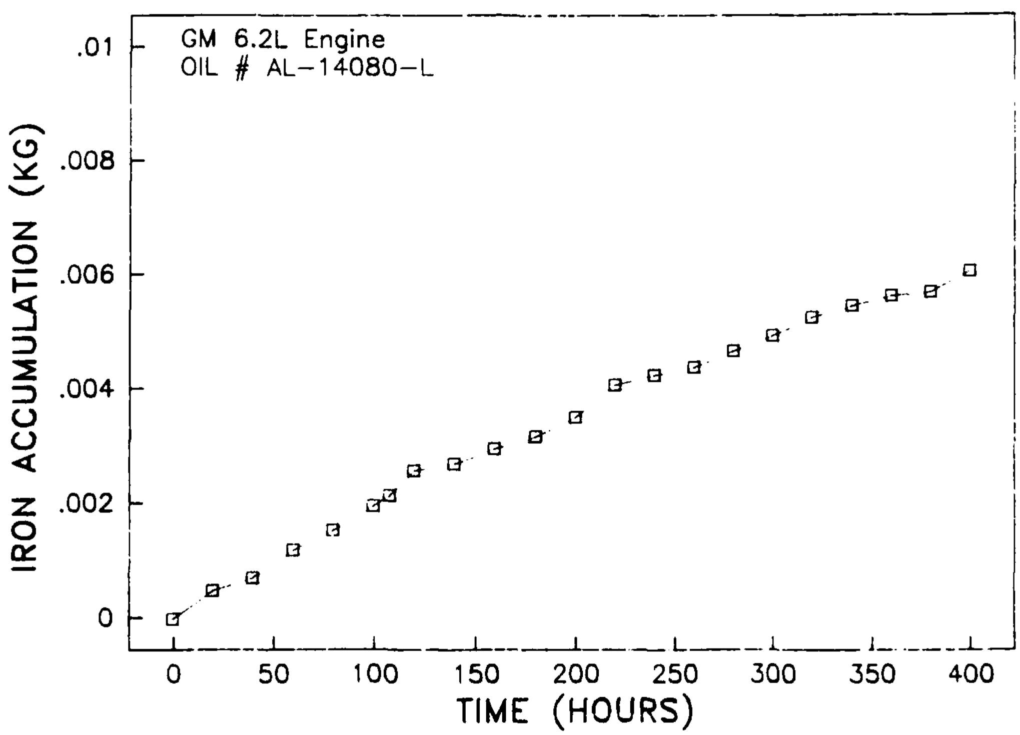
	1	2	3	4	5	6	7	8	Avg.
(ml/min) @ 1800 RPM									
Before Test	88.7	90.2	90.2	88.7	88.3	87.7	88.7	91.9	89.3
After Test	84.9	89.6	92.5	90.6	88.7	89.6	87.7	89.6	89.2

Overall Decrease: 0.1 ml/min

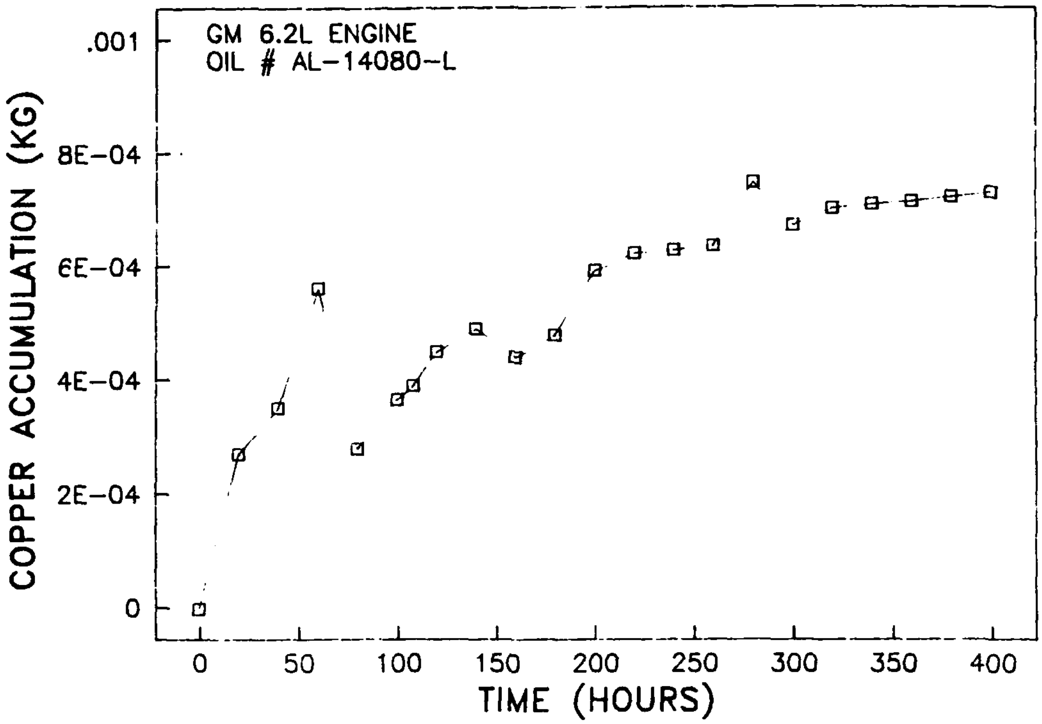
TOTAL OIL CONSUMPTION



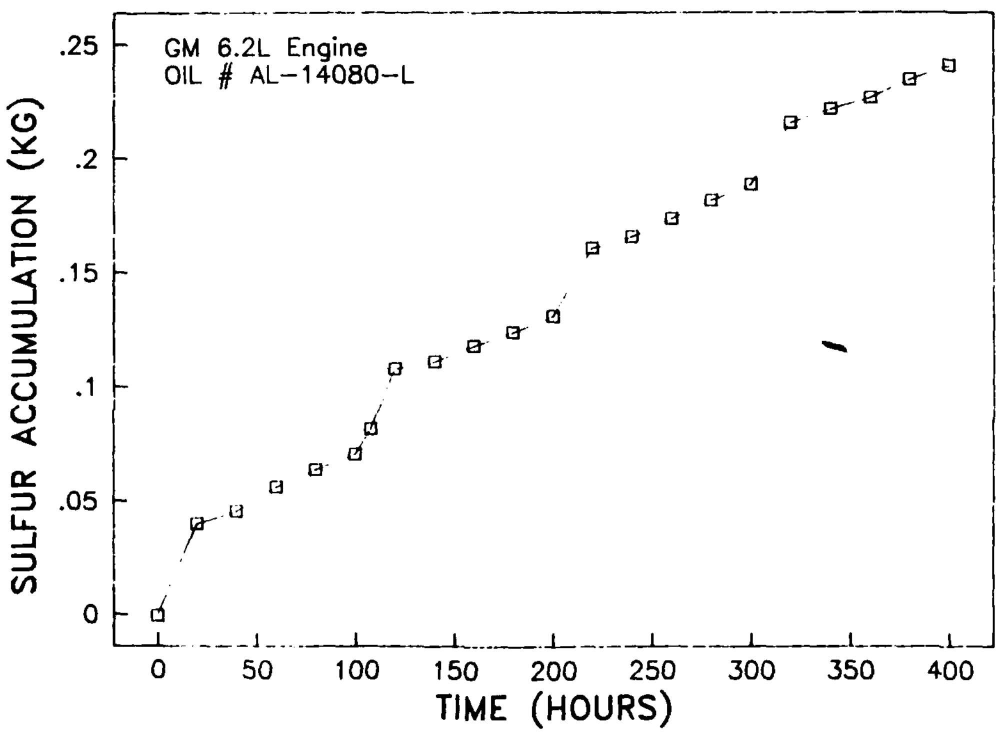
TOTAL IRON ACCUMULATION



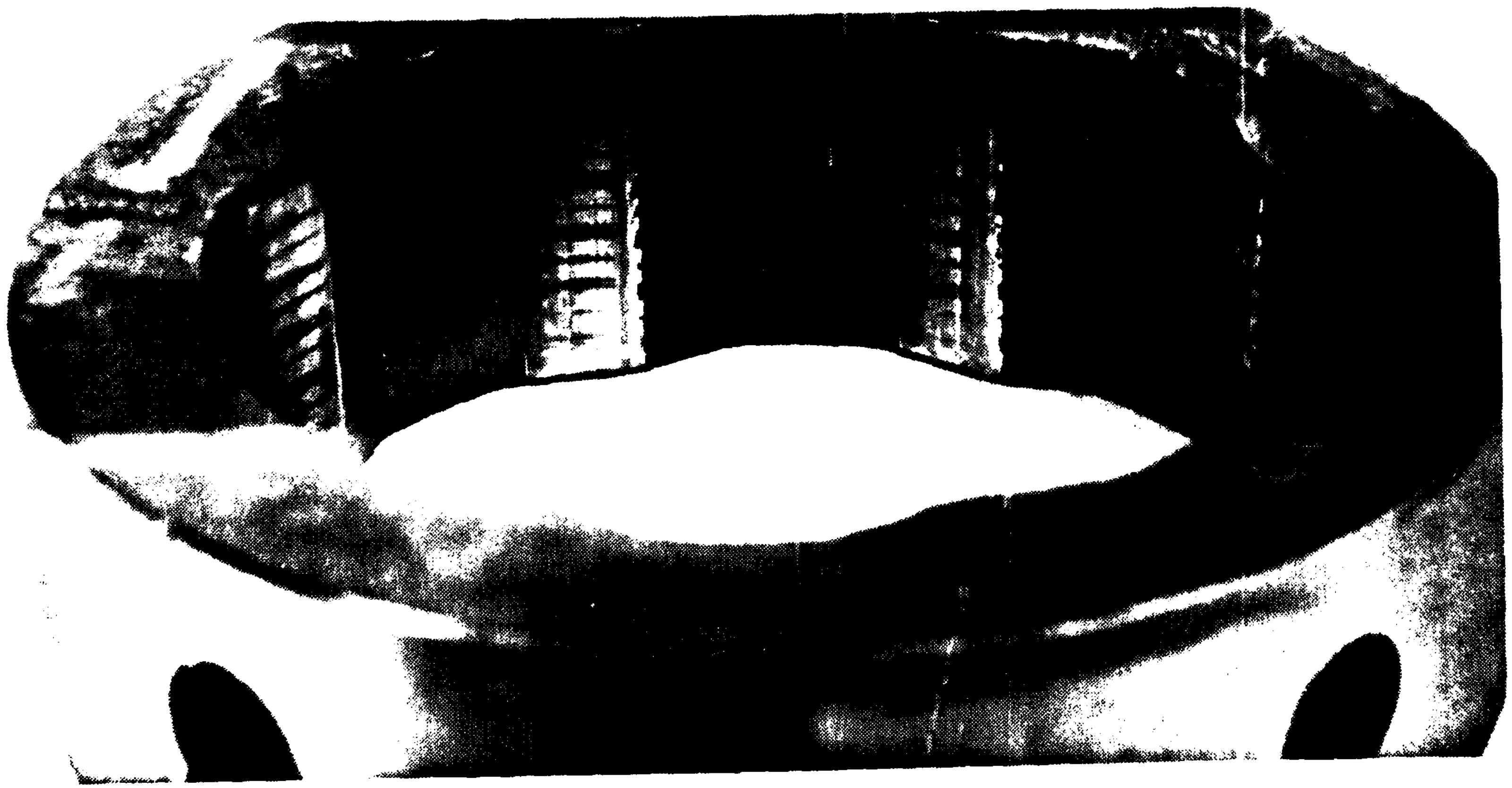
TOTAL COPPER ACCUMULATION



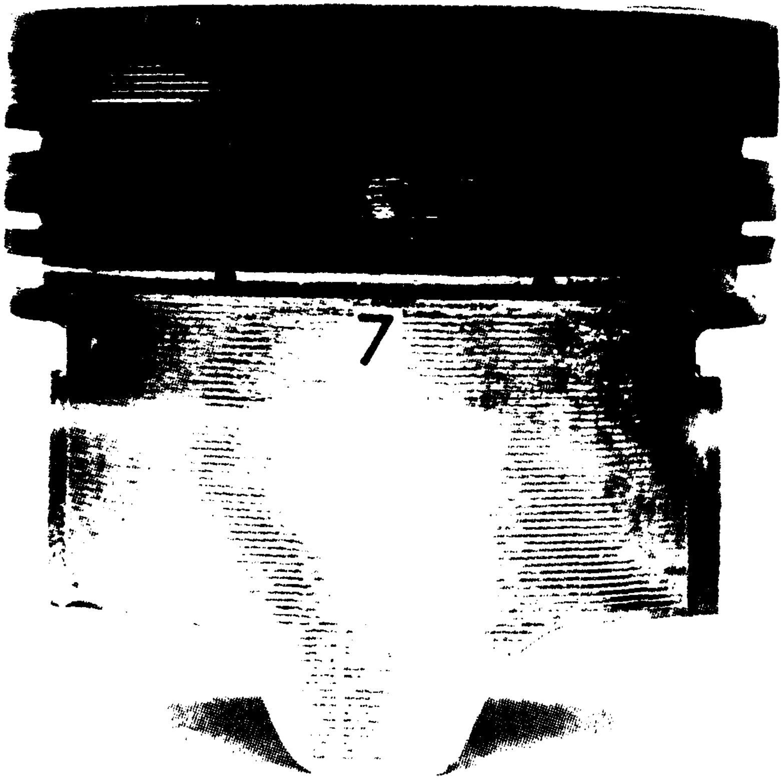
TOTAL SULFUR ACCUMULATION



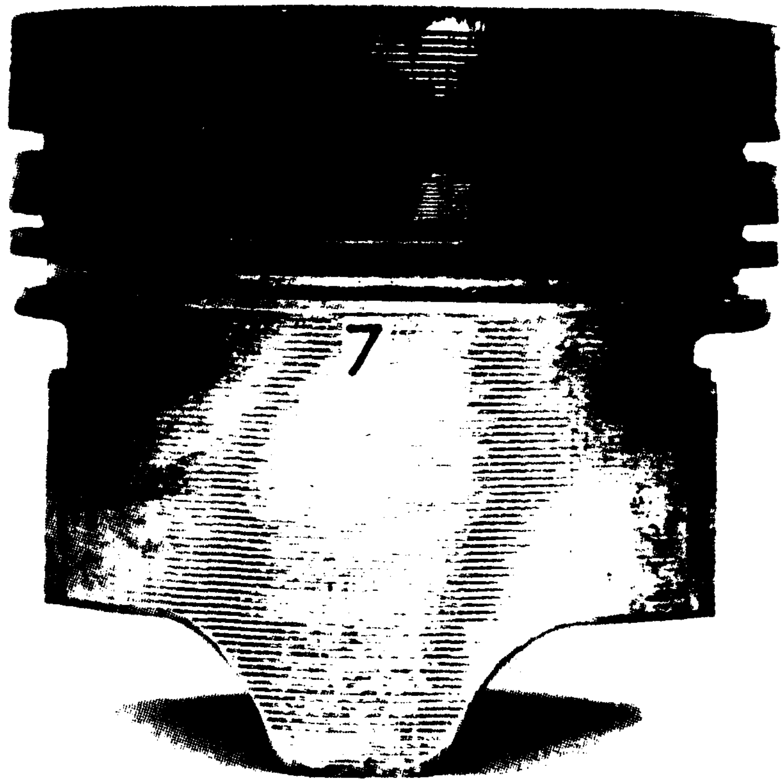
G.M. 6.2 LITER
FUEL EVALUATION
TEST 4 FUEL PUMP



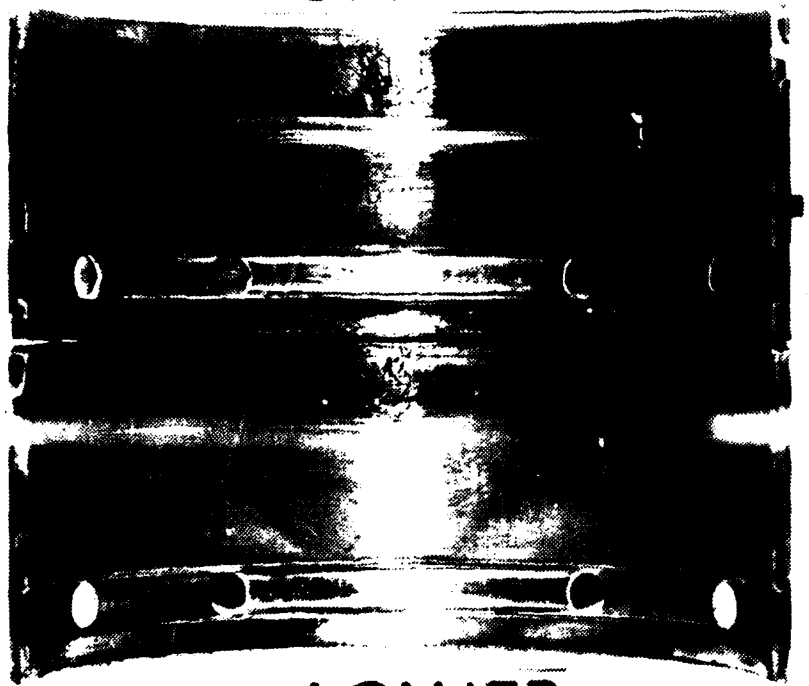
G.M. 6.2 LITER TEST #4
FUEL EVALUATION
(T)



G.M. 6.2 LITER TEST #4
FUEL EVALUATION
(AT)

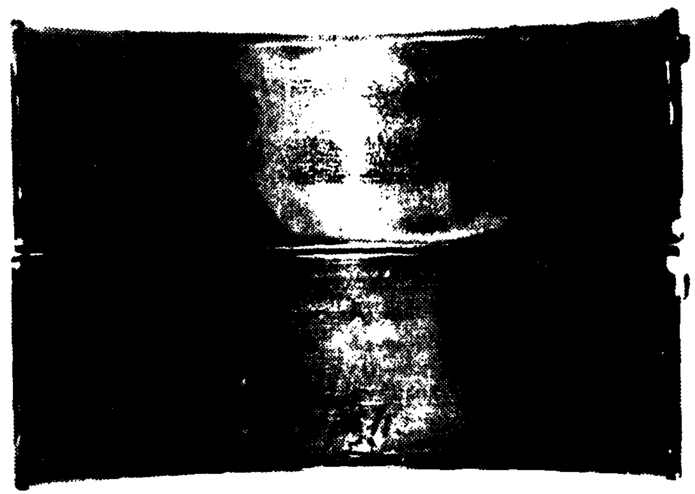


G.M. 6.2 LITER TEST # 4
FUEL EVALUATION
MAIN BEARINGS
UPPER

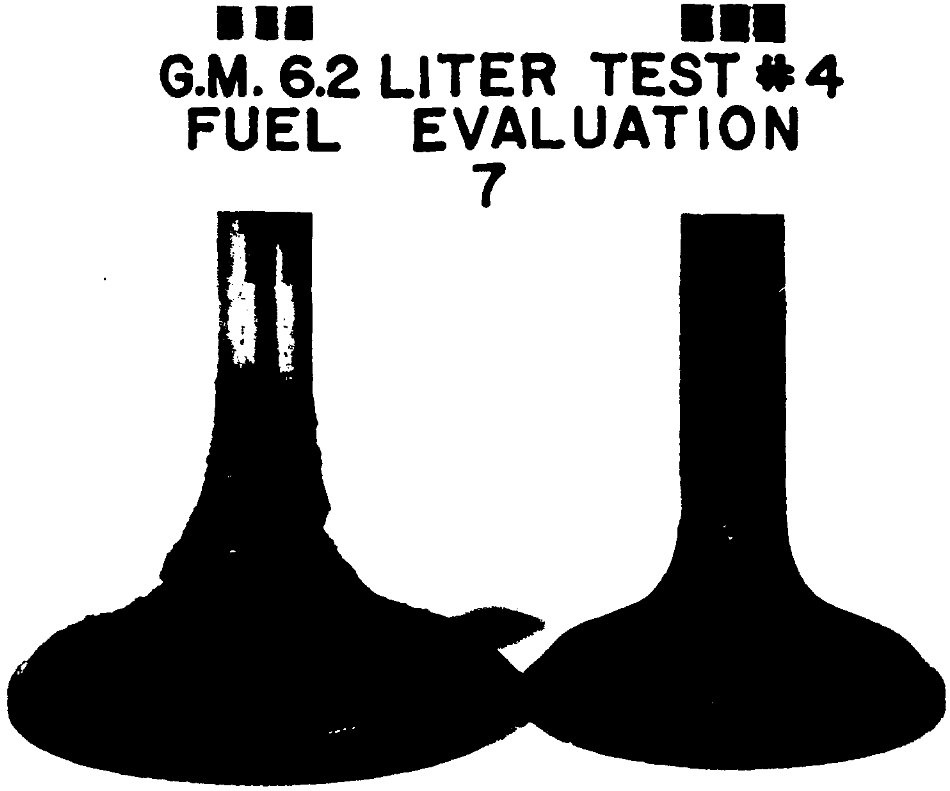


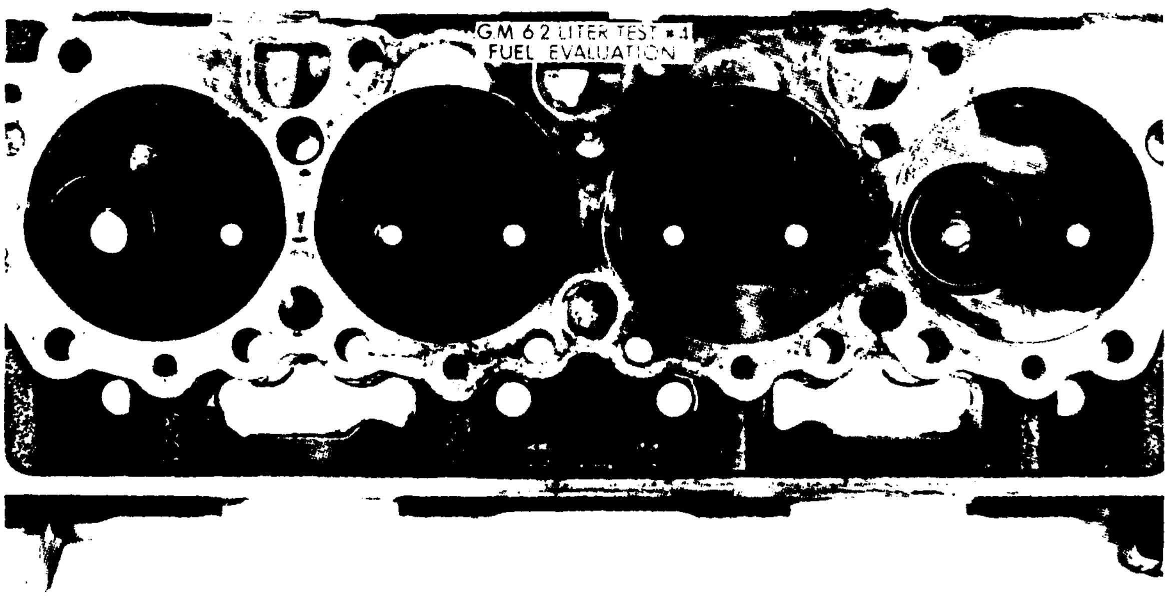
LOWER
5

G.M. 6.2 LITER TEST # 4
FUEL EVALUATION
ROD BEARINGS
UPPER



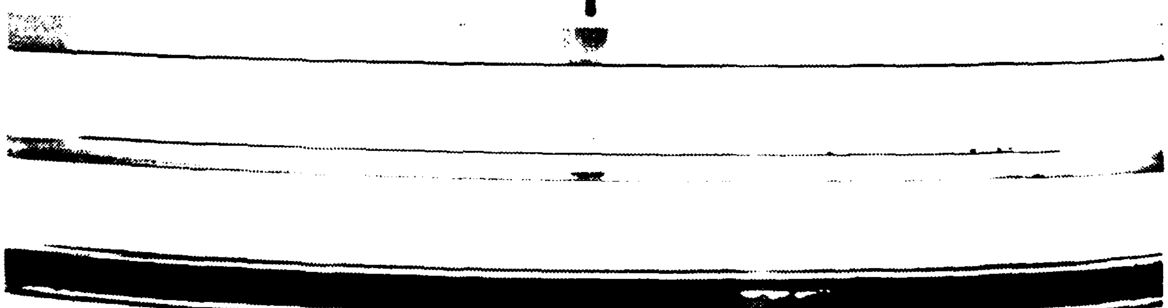
LOWER
7


G.M. 6.2 LITER TEST #4
FUEL EVALUATION
7


G.M. 6.2 LITER TEST #4
FUEL EVALUATION

7

G.M. 6.2 LITER TEST #4
FUEL EVALUATION
7



APPENDIX E
Test Data

Cummins NH-250 Engine
210-Hour Test
Cat Fuel*

*Use of designation "Cat 1-H" test fuel refers to Reference No. 2 Diesel Fuel, or simply Cat Fuel.

NH-250
CAT 1 H
ENGINE MEASUREMENTS

Cylinder Bore	Minimum	Maximum	Average	Specified Limits
Diameter	5.5002	5.5018	5.5010	————
Out of Round, Top	0.0001	0.0035	0.0014	0.0003 Max
Out of Round, Bottom	0.0000	0.0017	0.0011	0.002 Max
Piston Clearances				
Piston to Liner	0.0120	0.0130	0.0106	0.0099 - 0.0135
Piston Rings				
End Gap				
1	0.023	0.025	0.024	0.017 - 0.027
2	0.018	0.025	0.023	0.013 - 0.023
3	0.024	0.026	0.025	0.018 - 0.032
4	0.020	0.028	0.024	0.015 - 0.027
Piston Pin				
Pin to Piston Bushing	-0.0001	-0.0100	-0.0004	———— 0.003
Pin to Rod Bushing	0.0020	0.0030	0.0028	0.0020 - 0.0027
Main Bearing to Journal Clearance	0.0035	0.0045	0.0040	0.0015 - 0.0050
Connecting Rod Bearing to Journal Clearance	0.0035	0.0045	0.0042	0.0015 - 0.0045

NOTE: Measurements are in inches.

ANALYSIS OF CAT 1-H FUEL, BATCH 85-2 (AL-14069-F)

Test	AFLRL Data	Howell Data	Howell Cat 1-H Limit
Gravity, °API	34.5	34.5	32.0-35.0
Specific Gravity, 15.6/15.6°C	0.8524		
Distillation, °F(°C)			
IBP	402(206)	384(196)	Report
10% recovered	462(239)	467(242)	Report
50% recovered	517(269)	518(270)	500-530
90% recovered	611(322)	612(322)	580-620
EP	663(351)	664(351)	650-690
% recovered	99	---	(a)
% residue	1	---	(a)
Flash Point, °F(°C)	180(82)	180(82)	Report
Pour Point, °F(°C)	9(-13)	+5(-15)	+20 max
Cloud Point, °F(°C)	14(-10)	14(-10)	Report
Copper Corrosion, 3 hr at 210°F, Rating	1A	1A	2 max
Carbon Residue on 10% Bottoms, Ramsbottom wt%	0.11	0.13	0.20 max
Water and Sediment, vol%	<0.01	0.05	0.05 max
Neutralization Number, mg KOH/g	0.02	0.02	0.15 max
Ash, wt%	<0.01	0.006	0.01 max
Viscosity at 100°F (37.8°C), cSt	(b)	3.18	3.0-4.0
Viscosity at 40°C, cSt	2.98	(b)	(a)
Net Heat of Combustion, Btu/lb	18,279	(b)	(a)
MJ/kg	42,516	(b)	(a)
Cetane Number	52	51	45-51
Cetane Index	47	47	(a)
Carbon, wt%	86.24	---	(a)
Hydrogen, wt%	12.19	---	(a)
Sulfur, wt%	0.41	0.40	0.37-0.43

(a) - No requirement

(b) - Not determined

CUMMINS NH-250 ENGINE
OPERATING CONDITIONS SUMMARY
LUBRICANT: AL-14080-L
CAT 1-H FUEL: 14069-F

	Full Power Mode (2100 RPM)		Idle Mode (800 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed (rpm)	2100	0.00	699	27.1
Torque (ft-lb)	629.9	4.36	1.14	0.877
Fuel Consumption (lb/hr)	91.0	2.52	3.28	0.880
Observed Power (Bhp)	251.9	1.72	0.153	0.120
BSFC (lb/Bhp-hr)	0.3614	0.0994	37.5	44.4
Oil Gallery Pressure (psi)	46.9	3.12	81.1	1.08
Temperatures (°F)				
Water Jacket Inlet	168.9	1.76	98.3	1.68
Water Jacket Outlet	179.2	0.973	100.4	1.56
Oil Sump	245.6	2.56	136.1	2.23
Fuel Inlet	88.8	2.28	85.7	2.61
Air Inlet	101.7	4.78	88.9	4.32
Intake Manifold	105.1	4.37	89.8	4.16
Exhaust Temperatures (°F)				
Cylinder 1	1210	62.9	249.1	32.2
Cylinder 2	1242	65.0	251.5	33.0
Cylinder 3	1114	58.0	236.5	29.5
Cylinder 4	1212	62.1	245.2	32.2
Cylinder 5	1247	64.2	250.1	33.2
Cylinder 6	1099	57.9	230.5	28.8
Common	1014	59.4	225.1	27.6

NH-250
CAT 1 H
WEAR MEASUREMENTS

Cylinder Liner Bore Diameter Change

Position	1	2	3	4	5	6	Average
Top T-AT	0.0006	0.0004	0.0001	0.0003	0.0002	0.0002	0.0003
Top F-B	0.0012	0.0018	0.0017	0.0003	0.0014	0.0004	0.0011
Mid T-AT	0.0003	0.0003	0.0001	0.0002	0.0001	0.0004	0.0002
Mid F-B	0.0005	0.0004	0.0005	0.0004	0.0004	0.0002	0.0004
Bottom T-AT	0.0004	0.0001	0.0002	0.0001	0.0000	0.0001	0.0002
Bottom F-B	0.0000	0.0004	0.0002	0.0001	0.0002	0.0001	0.0002

Overall Average Change: 0.0004

Piston Ring End Gap Change

Rings							
1	0.002	0.003	0.004	0.000	0.000	0.001	0.0002
2	0.003	0.003	0.001	0.005	0.006	0.004	0.0004
3	0.001	0.003	0.001	0.008	0.002	0.000	0.0003
4	0.002	0.008	0.004	0.001	0.003	0.004	0.0003

Overall Average Change: 0.0003

Bearing Weight Loss

Rods							
Upper	0.0005	0.0039	0.0010	-0.0005	-0.0020	-0.0027	-0.0009
Lower	-0.0004	-0.0002	0.0005	0.0000	-0.0034	-0.0013	-0.0008

Overall Average Change: -0.0008

Main	1	2	3	4	5	6	7	Average
Upper	0.0067	0.0009	0.0055	0.0042	0.0079	0.0029	0.0087	0.0053
Lower	0.0039	0.0052	0.0027	0.0070	0.0066	0.0084	0.0122	0.0066

Overall Average Change: 0.0059 grams

NOTE: Measurements are in inches.

NH-250
CAT 1 H
POST TEST ENGINE CONDITION AND DEPOSITS

	Cylinder Number 1	2	3	4	5	6	Average
Cylinder Liner							
Liner Scuffing, % Area							
Thrust	0.0	0.0	0.0	0.0	0.0	1.0	0.2
Anti-Thrust				0.0			
% Total Area	0.0	0.0	0.0	0.0	0.0	0.5	0.0
						Overall:	0.0
Liner Polished, % Area							
Thrust				0.0			
Anti-Thrust				0.0			
% Total Area				0.0			
						Overall:	0.0
Pistons							
Ring Face Distress, (Demerits)							
1	0.0	0.0	0.0	0.5	0.0	0.0	0.10
2	0.0	0.0	0.0	0.75	0.25	0.5	0.25
3	0.0	0.0	0.0	1.25	0.0	0.75	0.33
						Overall:	0.23
Piston Skirt Rating				Normal			
Piston WTD Rating	113.495	102.333	116.550	113.610	174.915	125.295	124.366
Ring Sticking				None			
Combustion Chamber Deposits (grams)	0.7005	0.8169	0.7936	0.8247	0.7827	0.8206	0.7898
Exhaust Valves							
Deposits							
Head				1/2 AHC*			
Face				Clean			
Tulip	0.25	0.20	0.20	0.20	0.20	0.20	
Steam				1/4 AHC*			
Surface Condition							
Freeness in Guide				Free			
Head				Normal			
Face	Starting to burn one valve in #2 cylinder, other normal						
Seat				Normal			
Stem				Normal			
Tip				Normal			
Other Ratings							
Bearing Surface Condition							
Main				No Abnormalities			
Rod				No Abnormalities			

* 1/2 AHC; hard carbon, prefix indicates carbon depth with 1/4 AHC being the least to J the most.

NH-250
CAT 1 H
FUEL INJECTOR AND PUMP EVALUATION

	Cylinder Number						
	1	2	3	4	5	6	Average
Injector Flow Calibration (ml/100)							
Before	115.6	115.1	116.1	115.2	116.1	116.0	115.7
After	116.2	116.4	116.5	116.5	116.5	116.5	116.4

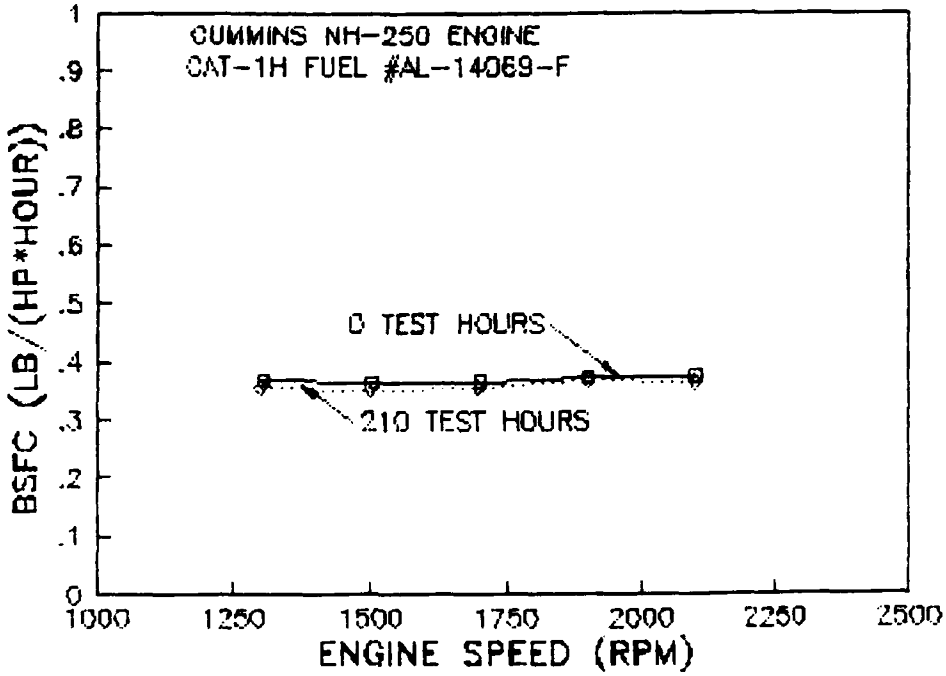
Overall Change: 0.7

	1	2	3	4	5	6	Average
Injector Needle Scuffing (% Area)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						Overall:	0.0

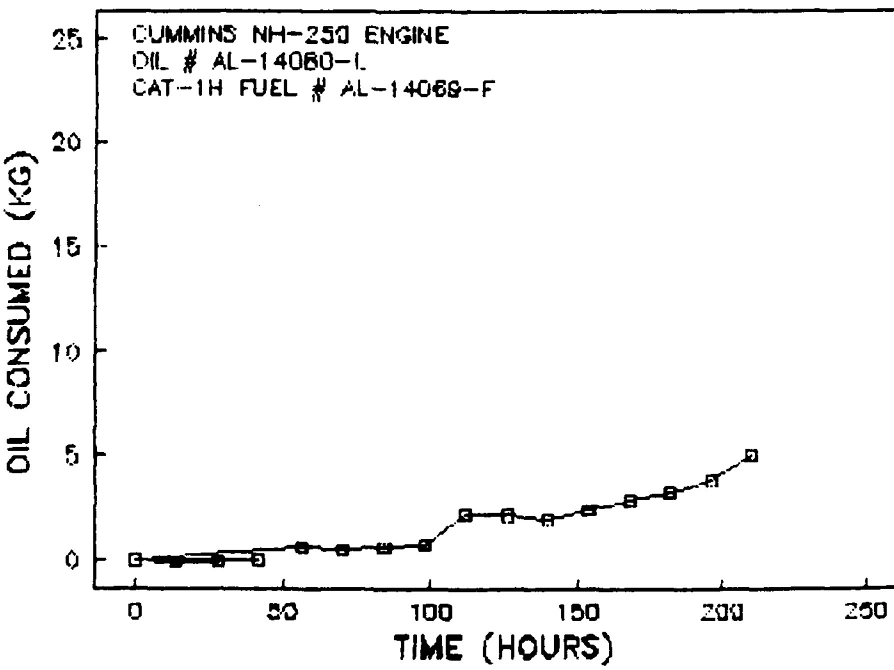
Pump Tests

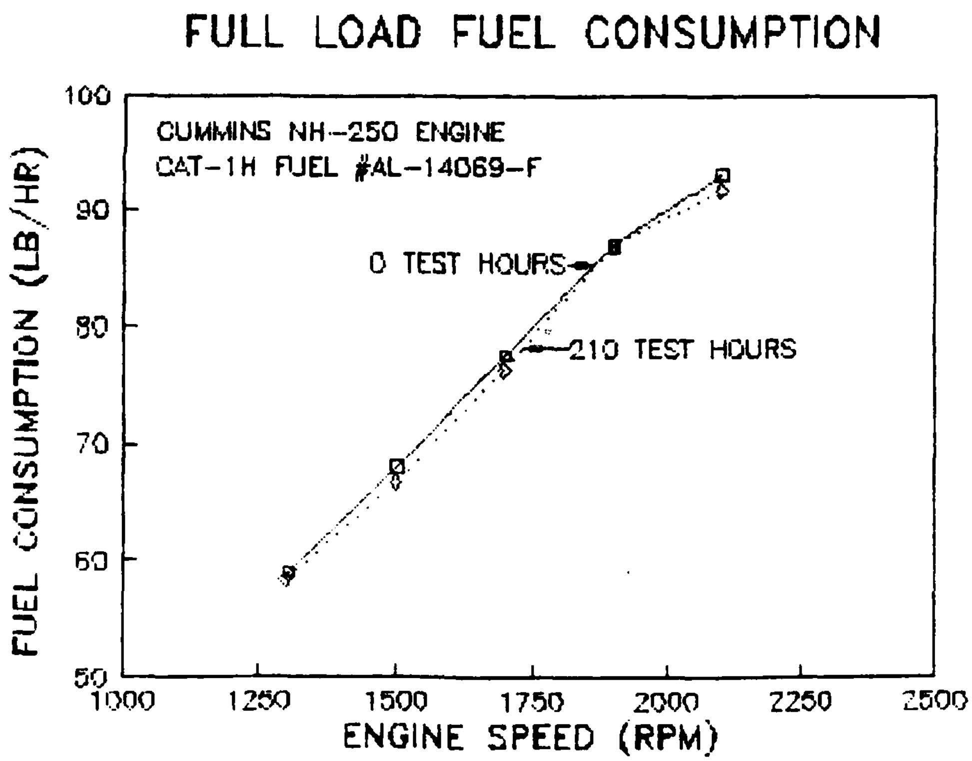
	Standards	Pre Test	Post Test	Change
Pump Fuel Pressure @ 2100 rpm	176-180	178	180	2
Fuel Cutoff (rpm)	2130-2150	2150	2148	-2
Throttle Leakage (cc/1000)	40-70 cc	50	72	22
Check Point #1 @ 1500 rpm (psi)	101-107 psi	110	107	-3
Check Point #2 @ 1000 rpm (psi)	50-58	62	58	-4
Idle Speed (500 rpm) Pressure (psi)	35	32	32	0

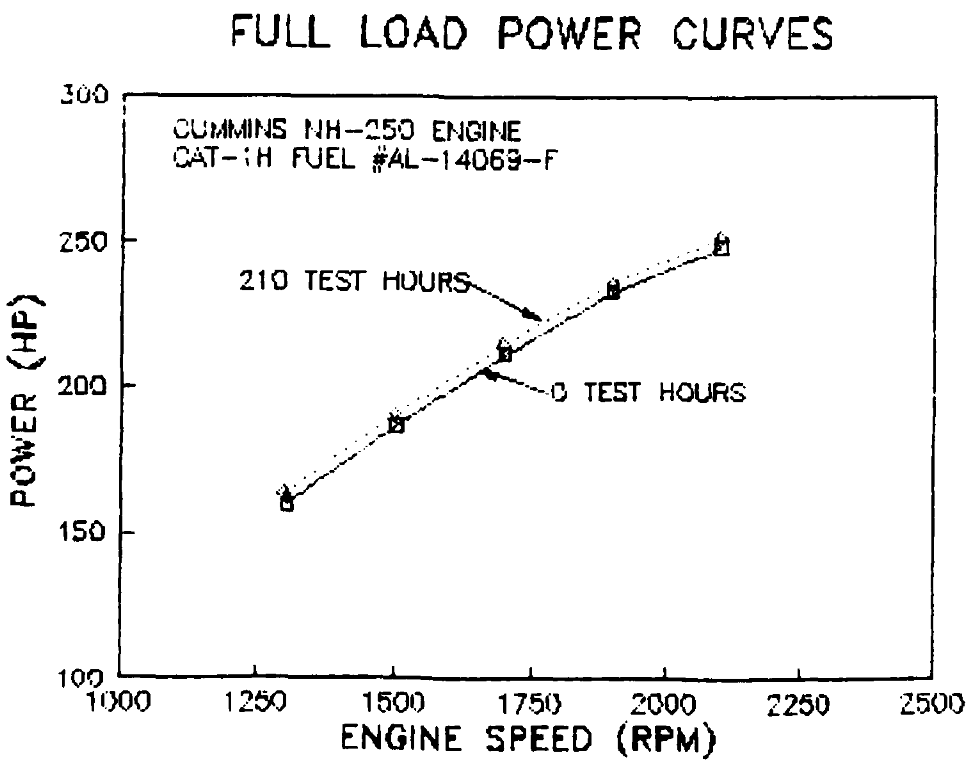
FULL LOAD BSFC CURVES



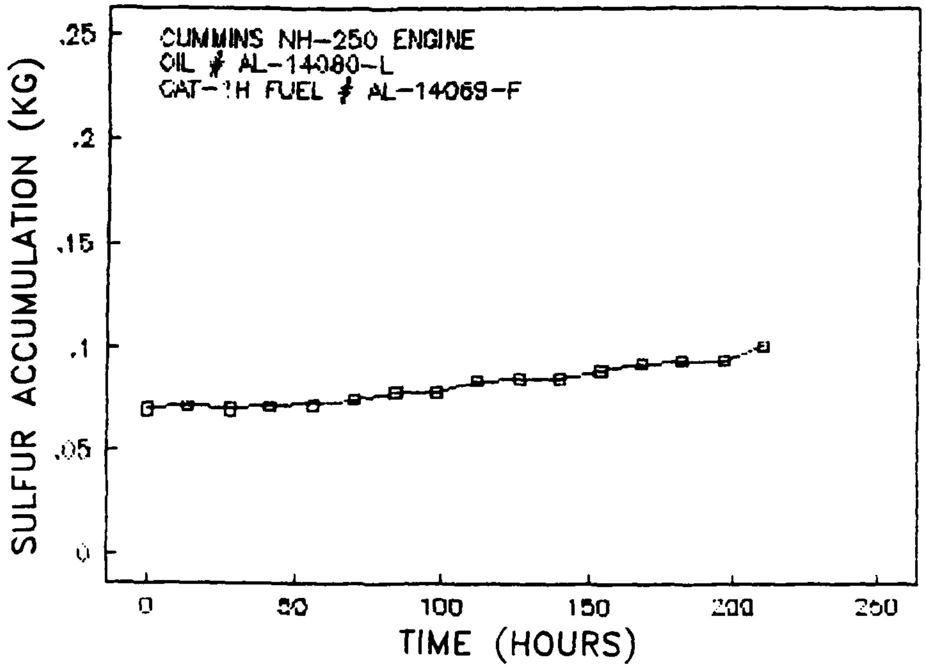
TOTAL OIL CONSUMPTION




FULL LOAD FUEL CONSUMPTION
CUMMINS NH-250 ENGINE
CAT-1H FUEL #AL-14069-F
0 TEST HOURS
210 TEST HOURS
FUEL CONSUMPTION (LB/HR)
ENGINE SPEED (RPM)
100
90
80
70
60
50
1000
1250
1500
1750
2000
2250
2500


FULL LOAD POWER CURVES
CUMMINS NH-250 ENGINE
CAT-1H FUEL #AL-14069-F
210 TEST HOURS
0 TEST HOURS
POWER (HP)
ENGINE SPEED (RPM)
300
250
200
150
100
1000
1250
1500
1750
2000
2250
2500

TOTAL SULFUR ACCUMULATION



APPENDIX F
Test Data and Photographs

Cummins NH-250 Engine
210-Hour Test
JP-8 Fuel

NHC 250
JP-8
LOG OF UNSCHEDULED EVENTS

Test Time Hours	EVENT
49	o Engine Shutdown Due To Electrical Power Failure In The Building
195	o Engine Coolant Temperature Controller Failed

NH-250
JP-8
ENGINE MEASUREMENTS

Cylinder Bore	Min.	Max.	Avg.	Specified Limits
Diameter	5.4999	5.5016	5.5007	
Out of Round, Top	0.0005	0.0016	0.0009	0.0003 max
Out of Round, Bottom	0.0000	0.0002	0.0001	0.002 max
Piston Clearances				
Piston to Liner	0.0119	0.0129	0.0124	0.0099 - 0.0135
Piston Rings				
End Gap				
1	0.023	0.026	0.025	0.017 - 0.027
2	0.019	0.022	0.021	0.013 - 0.023
3	0.019	0.023	0.021	0.018 - 0.032
4	0.020	0.026	0.023	0.015 - 0.027
Piston Pin				
Pin to Piston Bushing	0.0000	0.0001	0.0000	0.003
Pin to Rod Bushing	0.0025	0.0029	0.0026	0.0020 - 0.0027
Main Bearing to Journal Clearance	0.0051	0.0062	0.0057	0.0015 - 0.0050
Connecting Rod Bearing to Journal Clearance	0.0047	0.0052	0.0049	0.0015 - 0.0045

Measurements are in inches.

PROPERTIES OF JP-8 OBTAINED FROM SUNTECH

PROPERTY	METHOD	REQUIREMENTS OF NATO F-34	AL-14216-F
Color	D 156	(a)	+15(Saybol
Total Acid Number, mg KOH/g	D 3242	0.015 max	0.005
Aromatics, vol%	D 1319	25.0 max	19.0
Olefins, vol%	D 1319	5.0 max	0
Sulfur, total wt % (XRF)	D 2622	0.3	<0.01
Mercaptan sulfur, wt%	D 3227	0.001max	0.0002
Distillation, GC, *C	D 2887		
Initial boiling point		(a)	136.2
10 % recovered		186 max	169.3
20 % recovered		(a)	180.6
50 % recovered		(a)	205.6
90 % recovered		(a)	236.9
End point		330 max	262.6
Flash Point, *C	D 93	38 min	56
Gravity, *API	D 1298	37 - 51	40.3
Density, kg/L at 15*C	D 1298	0.775 - 0.840	0.8232
Freezing point, *C	D 2386	-50 max	-55
Kin viscosity at -20*C, cSt	D 445	8.0 max	4.14
Net heat of combustion,MJ/kg(Btu/lb)		42.8(18,400) min	43.106 (18,532)
Hydrogen content, wt %		13.5 min	13.69
Smoke point, mm	D 1322	19 min	22.2
Copper corrosion, 2hr @ 100*C	D 130	1B max	1A
Thermal stability (JFTOT),Code	D 3241	<3	1
Change in pressure drop, mm Hg		25 max	0
Existent gum, mg/100mL	D 381	7.0 max	0.2
Particulate matter, mg/L	D 2276	1.0 max	1.1 (b)
Water reaction, interface rating	D 1094	1b	1b
Water separation index, modified	D 2550	70 max	
Fuel system icing inhibitor		0.10 - 0.15	0.01,0.04
Fuel electrical conductvty, pS/m	D 2624	200-600	170,90
Filtration time, minutes	Apdx A MIL-T-5624	15 max	72
Cetane Number		NR(c)	41
BOCLE, scar diameter, mm		NR	0.34

(a) Report
(b) Outside of specification limits.
(c) No requirement.

CUMMINS NH-250 ENGINE
OPERATING CONDITIONS SUMMARY
LUBRICANT: AL-14080-L
JP-8 FUEL: AL-14216-F

	Full Power Mode (1200 RPM)		Idle Mode (800 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed (rpm)	2100	0.927	677.7	5.18
Torque (ft-lb)	622.9	41.1	--*	--
Fuel Consumption (lb/hr)	95.6	1.31	3.13	1.15
Observed Power (Bhp)	249.1	16.4	--	--
BSFC (lb/Bhp-hr)	0.3913	0.1171	--	--
Oil Gallery Pressure (psi)	49.1	0.960	78.0	2.04
Temperatures (°F)				
Water Jacket Inlet	166.9	0.957	100.8	13.2
Water Jacket Outlet	178.3	0.751	101.8	2.06
Oil Sump	254.8	1.97	143.4	2.39
Fuel Inlet	92.0	4.03	87.8	3.84
Air Inlet	103.8	4.74	90.7	4.01
Intake Manifold	106.5	4.28	91.8	3.84
Exhaust Temperatures (°F)				
Cylinder 1	1249	20.0	195.0	27.1
Cylinder 2	1318	24.1	219.6	27.9
Cylinder 3	1202	22.5	221.7	25.6
Cylinder 4	1258	19.3	197.7	29.3
Cylinder 5	1300	20.8	198.5	28.6
Cylinder 6	1161	20.6	200.9	24.7
Common	1060	27.2	193.3	94.4

*Data not available

NHC-250
JP-8
WEAR METALS BY XRF
LUBRICANT: AL-14080-L

Test Time Hours	Wear Metals ppm Fe	Cu	Cr	Pb	S%
0	10	< 10	< 15	< 60	0.42
14	10	10	15	60	0.45
28	10	10	15	60	0.45
42	21	10	15	60	0.46
56	11	10	15	60	0.46
70	16	10	15	60	0.43
84	10	10	15	60	0.43
98	24	10	15	60	0.43
112	32	10	15	60	0.43
126	39	10	15	60	0.43
140	39	10	15	60	0.42
154	24	10	15	60	0.42
168	34	10	15	60	0.41
182	45	10	15	60	0.43
196	46	10	15	60	0.42
210	53	10	15	60	0.40

NHC-250
JP-8
LUBRICANT: AL-14080

	ASTM Method	Test Time, Hours 0	70	140	210
Kinematic Viscosity @ 40°C cSt	D 445	97.13	95.13	102.58	111.11
Kinematic Viscosity @ 100°C cSt	D 445	11.04	10.78	11.54	12.69
Total Acid Number mg KOH/g	D 664	2.51	2.58	2.69	3.88
Total Base Number mg KOH/g	D 664	6.49	4.07	3.28	2.71
Pentane B Insolubles wt%	D 893	--	0.11	0.56	1.70
Toluene B Insolubles wt%	D 893	--	0.10	0.48	1.54
Flash Point, °C	D 92	230	233	233	232

NH-250
JP-8
WEAR MEASUREMENTS

Position	Cylinder Liner Bore Diameter Change 1	2	3	4	5	6	Avg.
Top T-AT	0.0001	0.0003	0.0002	0.0002	0.0002	0.0003	0.0002
Top F-B	0.0006	0.0004	0.0006	0.0006	0.0005	0.0007	0.0006
Mid T-AT	0.0005	0.0006	0.0002	0.0003	0.0003	0.0004	0.0004
Mid F-B	0.0002	0.0001	0.0003	0.0004	0.0003	0.0003	0.0003
Bot-T-AT	0.0005	0.0006	0.0003	0.0003	0.0003	0.0003	0.0006
Bot F-B	0.0000	0.0000	0.0005	0.0004	0.0003	0.0003	0.0003

Overall: 0.0004

Ring	Piston Ring End Gap Change						
1	0.0004	0.000	0.001	0.000	0.000	0.000	0.0001
2	0.000	0.007	0.005	0.008	0.011	0.008	0.0007
3	0.000	0.010	0.010	0.007	0.005	0.006	0.0006
4	0.002	0.002	0.002	0.001	0.002	0.003	0.0002

Overall average change: 0.0003

Rods	Bearing Weight Loss						
Upper	0.0069	0.0060	0.0095	0.0125	0.0149	0.0157	0.0109
Lower	0.0087	0.0083	0.0091	0.0083	0.0077	0.0096	0.0086

Overall average change: 0.0098

Mains	1	2	3	4	5	6	7	Avg.
Upper	0.0057	0.0058	0.0049	0.0040	0.0061	0.0091	0.0042	0.0057
Lower	0.0057	0.0063	0.0080	0.0044	0.0061	0.0082	0.0057	0.0063

Overall average change: 0.0060 grams

Total Overall Change: 0.0079

Measurements are in inches.

NH-250
JP-8
POST TEST ENGINE CONDITION AND DEPOSITS

Cylinder Liner	Cylinder Number 1	2	3	4	5	6	Avg.
Liner Scuffing, % Area							
Thrust				0.0			
Anti-Thrust				0.0			
% Total Area				0.0			
Liner Polish, % Area							
Thrust				0.0			
Anti-Thrust				0.0			
% Total Area				0.0			
Pistons							
Ring Face Distress, (demerits)							
1				0.0			
2				0.0			
3				0.0			
4				0.0			
Piston Skirt Ratings				No abnormalities			
Piston WTD Rating	157.950	122.400	138.625	120.375	172.750	168.250	146.725
Ring Stretching				None			
Combustion Chamber Deposits (grams)	0.1872	0.2370	0.2412	0.4699	0.5850	0.2397	0.3267
Exhaust Valves							
Deposits				1/4 AHC*			
Head				1/4 AHC			
Face				0.25			
Stem				Clean			
Surface Conditions							
Freeness in Guide				Free			
Head				Normal			
Face				Normal			
Seat				Normal			
Stem				Normal			
Tip				Normal			
Other Ratings							
Beaming Surface Conditions							
Main				No abnormalities			
Rod				No abnormalities			

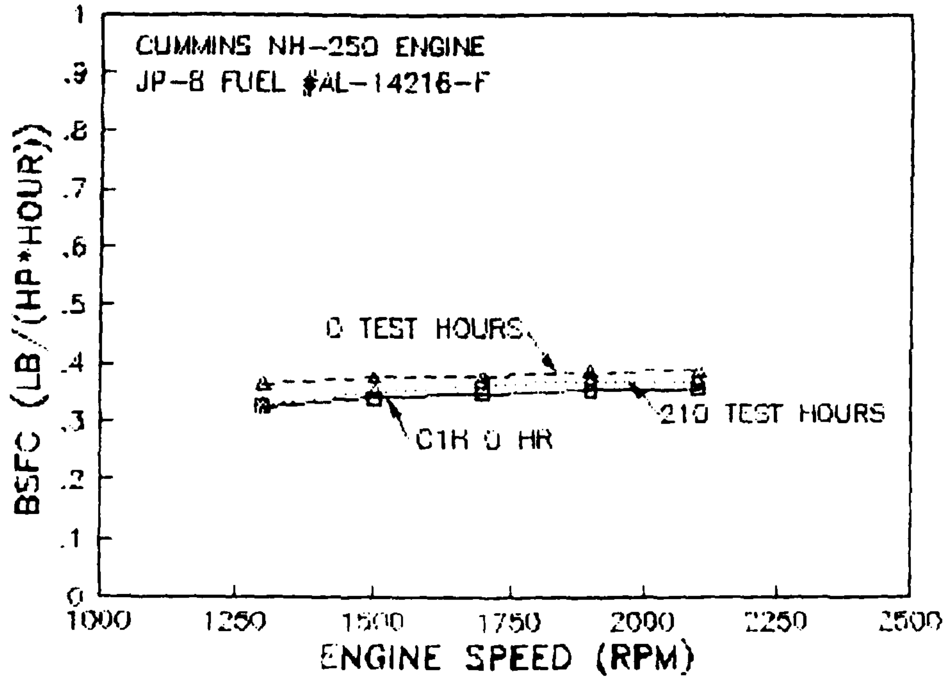
NH-250
JP-8
FUEL INJECTOR AND PUMP EVALUATION

Injector Flow Calibration (ml/100)	Cylinder Number 1	2	3	4	5	6	Avg.
Before	114.6	113.5	113.0	113.9	116.3	115.5	114.5
After	115.2	115.3	114.3	114.6	115.8	115.2	115.1
Change	0.6	1.8	1.3	0.7	-0.5	-.3	0.6

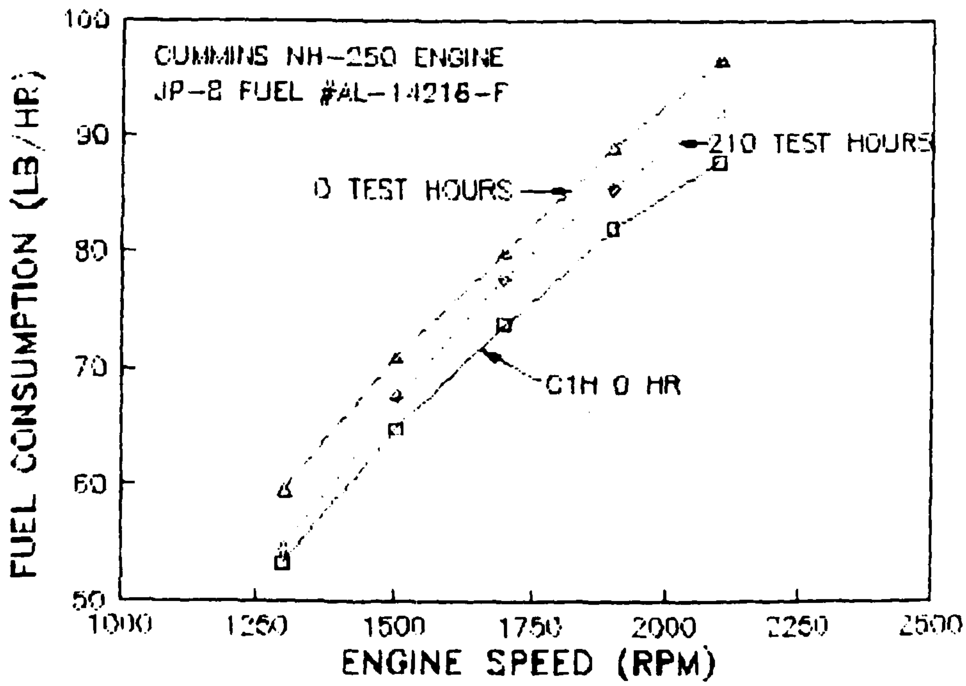
Injector Needle
Scuffing (% arcs) 0.0

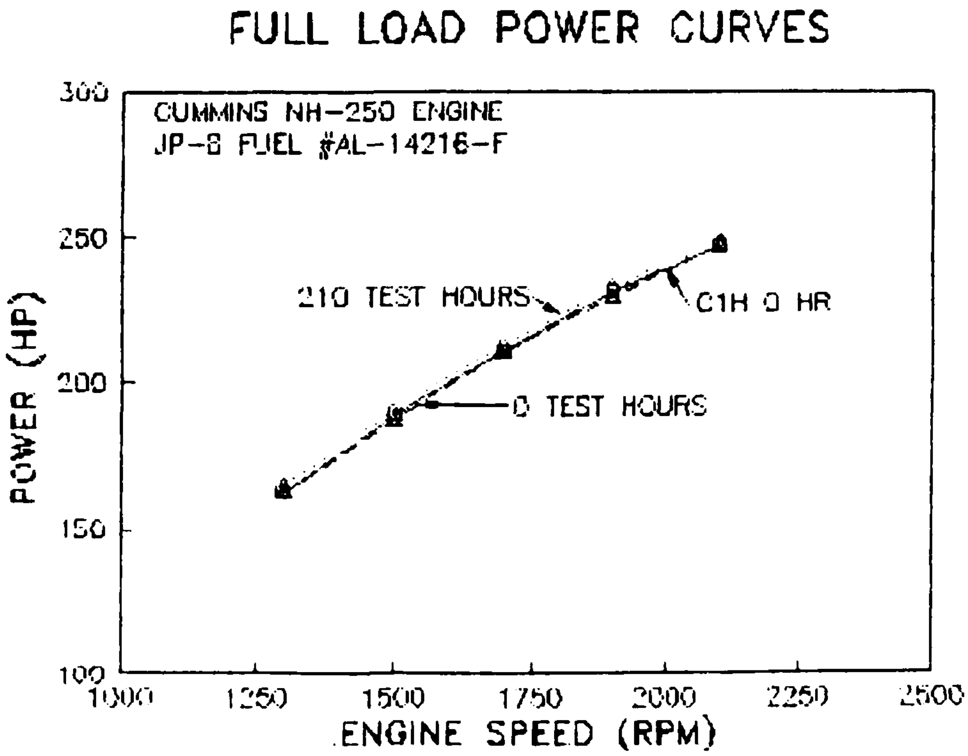
Pump Tests	Standards	Pre	Post	Change
Pump Fuel Pressure @ 2100 rpm	176-180	176	180	4.0
Fuel Cutoff (rpm)	2130-2150	2130	2150	20
The Hle Leakage (cc/1000)	40-70	48	36	-8
Check Point #1 @1500 rpm (psi)	101-107	105	110	5
Check Point #2 @ 1000 rpm (psi)	50-58	60	59	-1
Idle Speed (500 rpm)	35	29	30	1

FULL LOAD BSFC CURVES

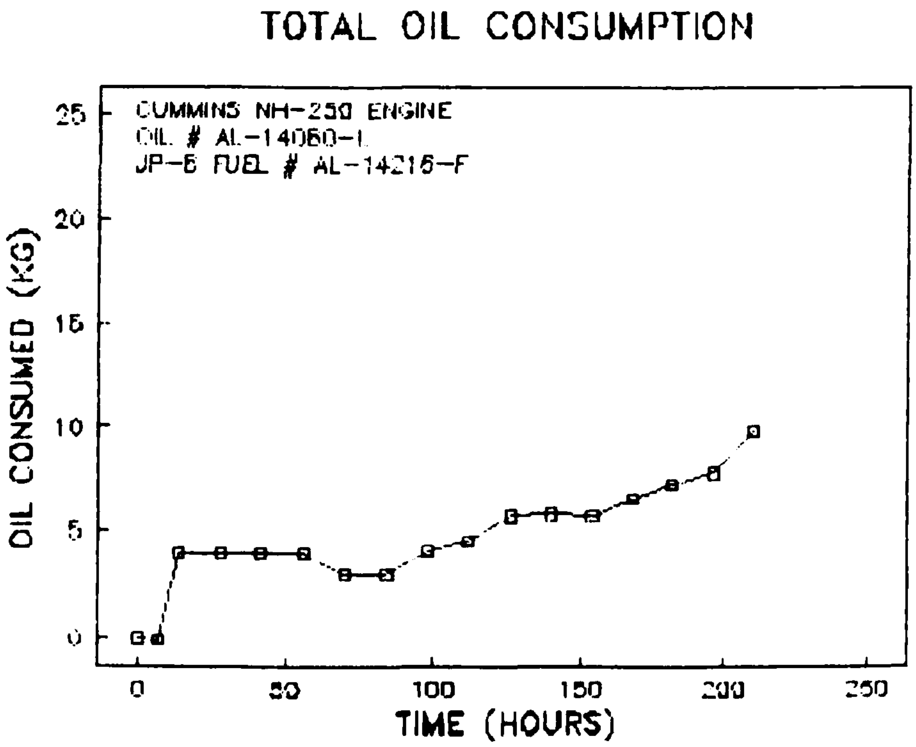


FULL LOAD FUEL CONSUMPTION



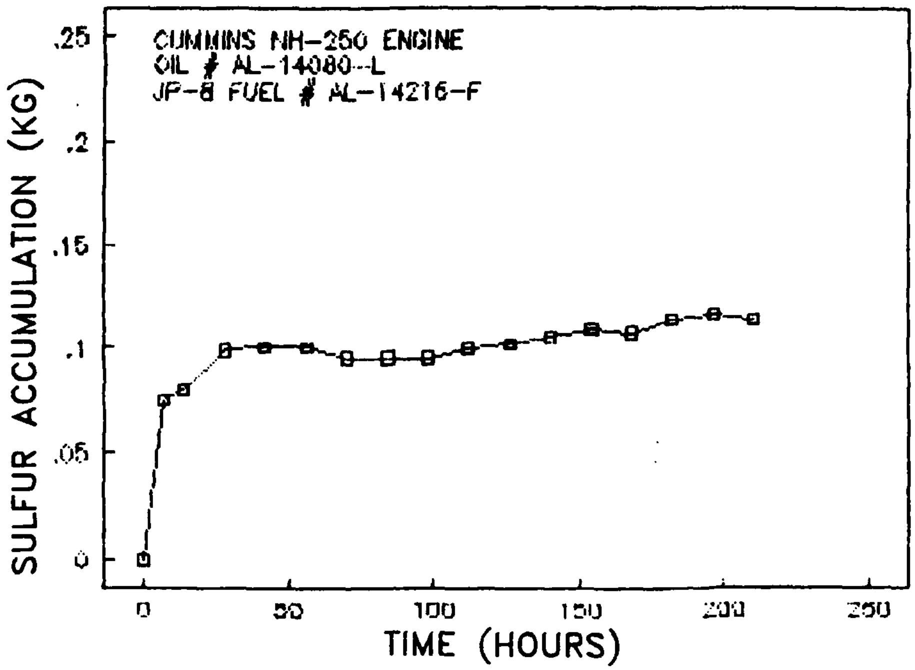


FULL LOAD POWER CURVES
CUMMINS NH-250 ENGINE
JP-8 FUEL #AL-14216-F
210 TEST HOURS
C1H 0 HR
0 TEST HOURS
POWER (HP)
ENGINE SPEED (RPM)
300
250
200
150
100
1000
1250
1500
1750
2000
2250
2500



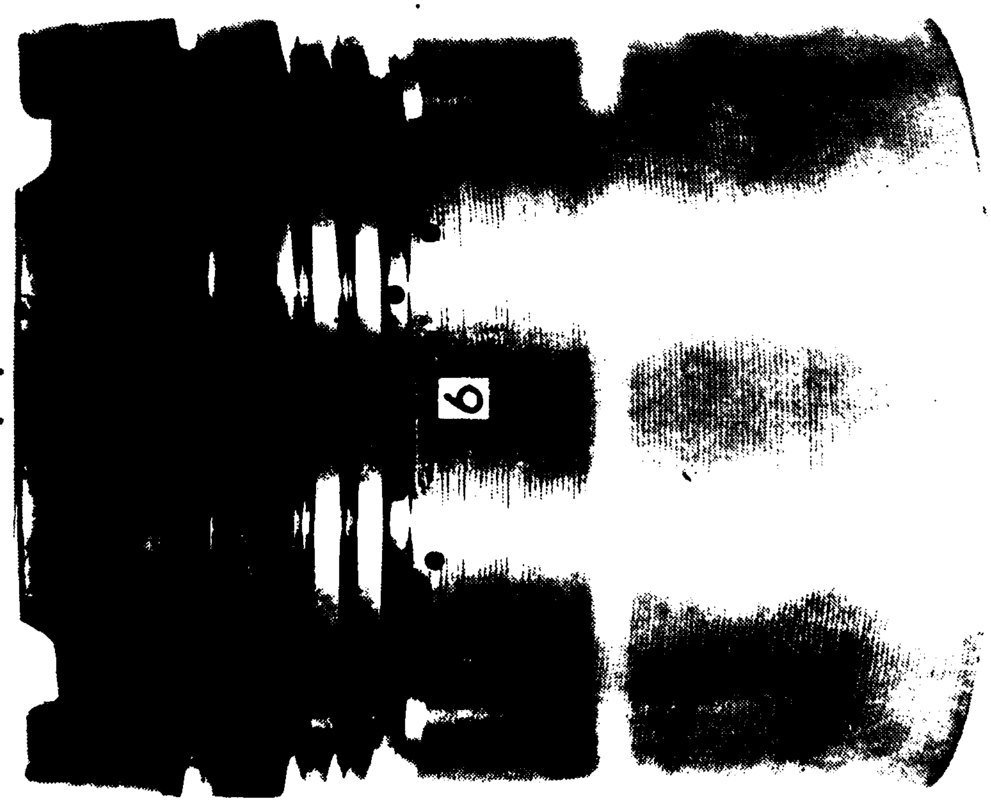
TOTAL OIL CONSUMPTION
CUMMINS NH-250 ENGINE
OIL # AL-14060-L
JP-8 FUEL # AL-14216-F
OIL CONSUMED (KG)
TIME (HOURS)
25
20
15
10
5
0
0
50
100
150
200
250

TOTAL SULFUR ACCUMULATION

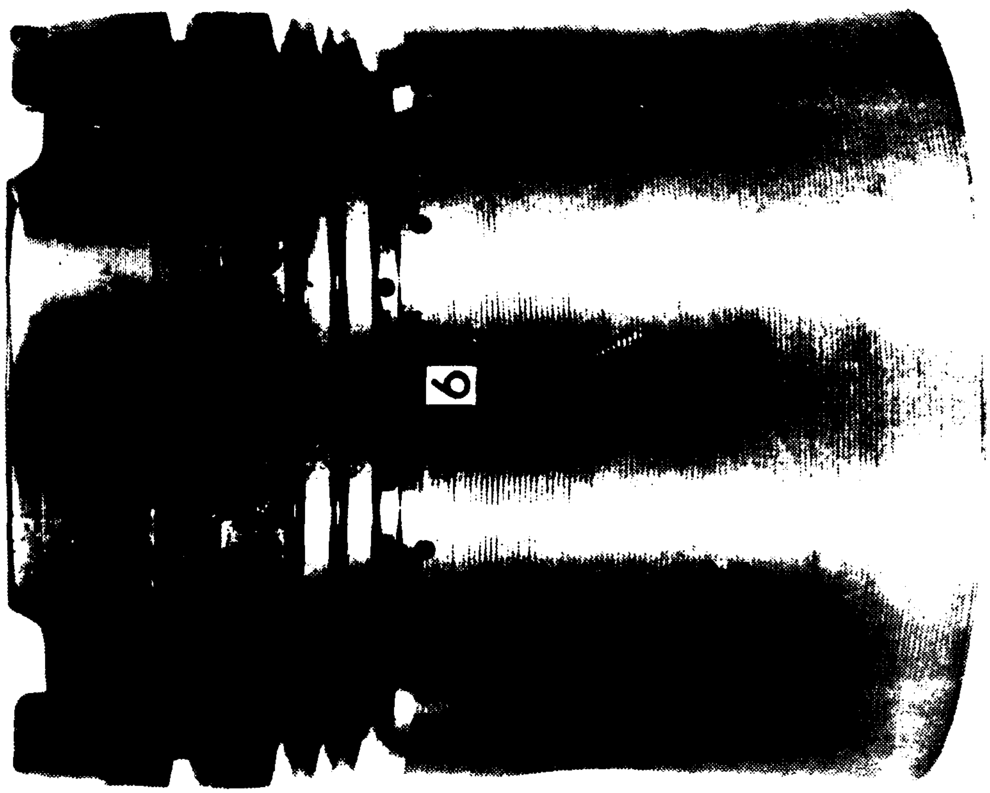


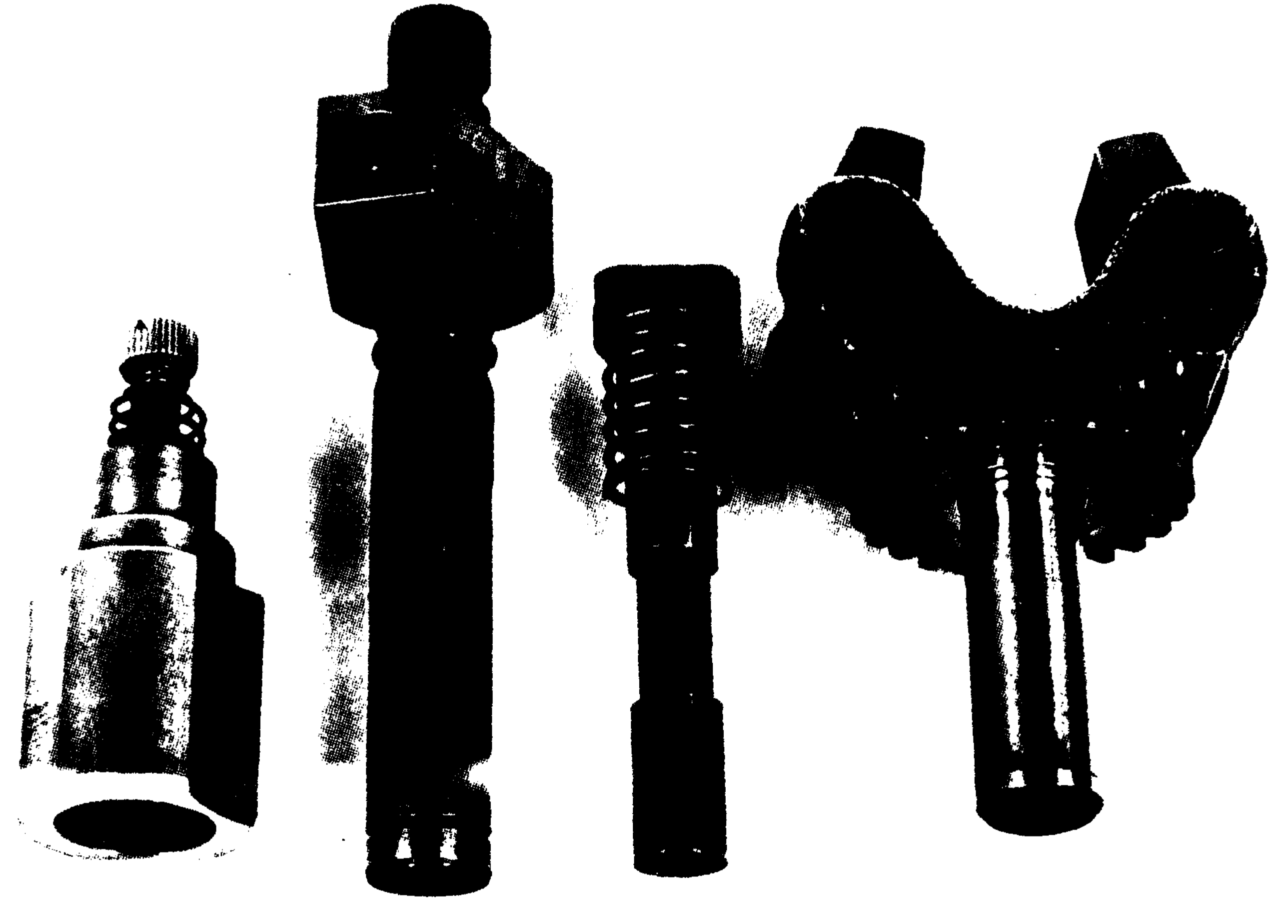

NHC - 250 CUMMINS
FUEL EVALUATION
TEST #2 FUEL PUMP

NHC-250 TEST #2
FUEL EVALUATION
(T)

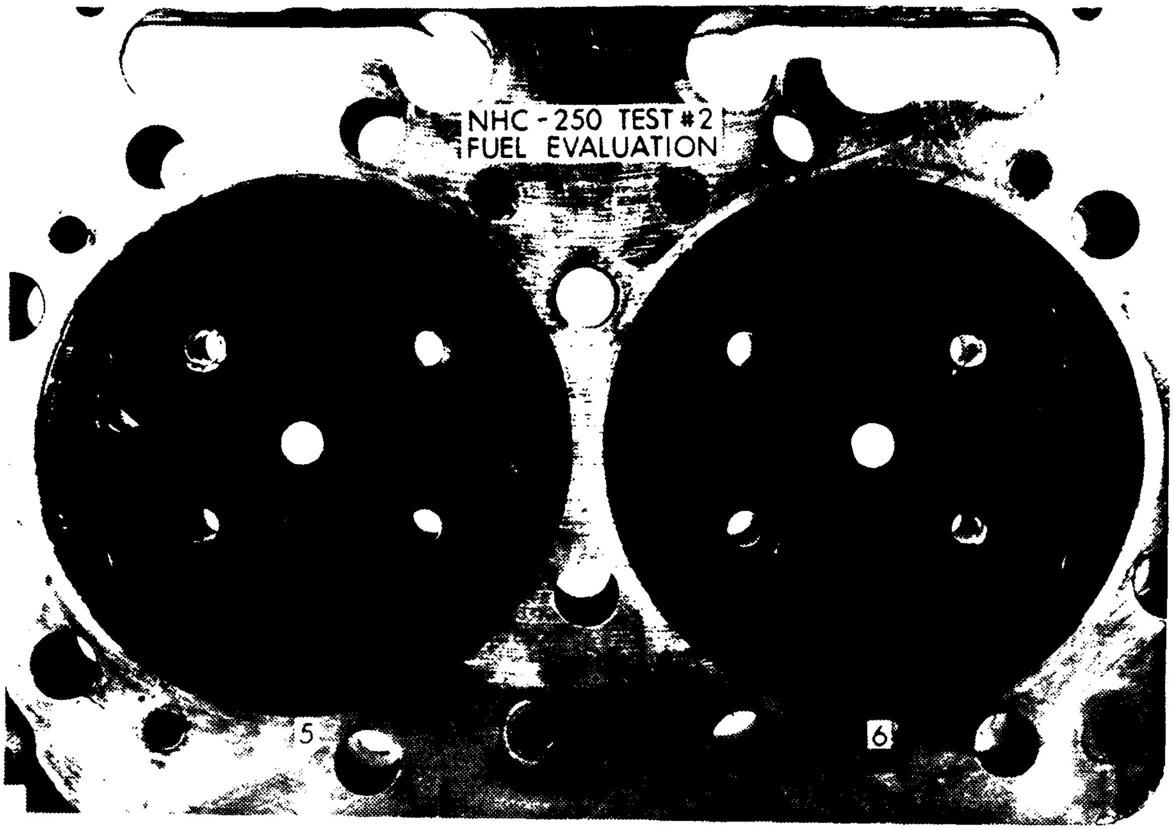


NHC-250 TEST #2
FUEL EVALUATION
(AT)

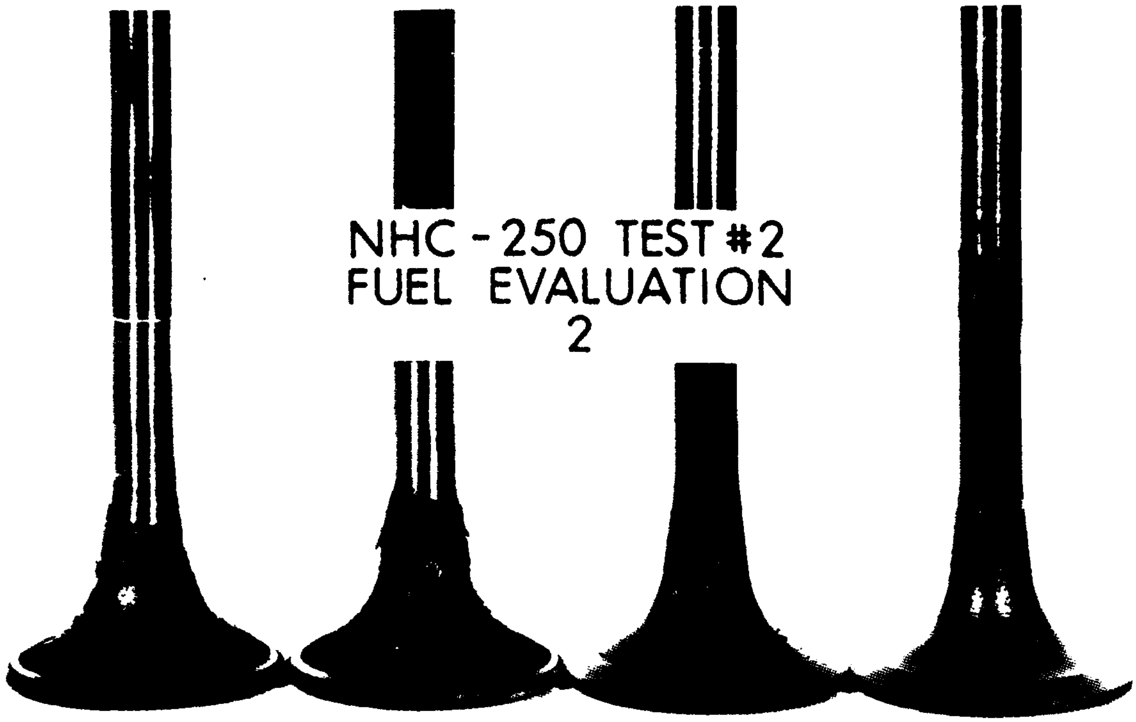


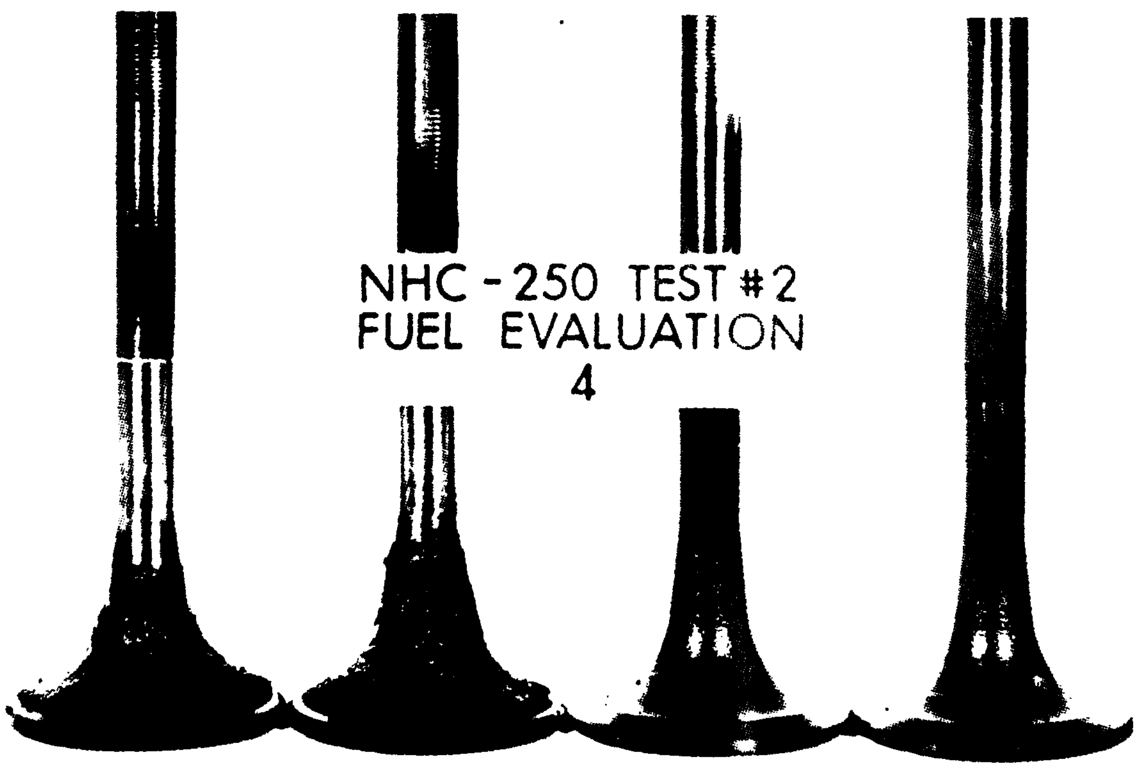


NHC-250 CUMMINS
FUEL EVALUATION
TEST #2 FUEL PUMP



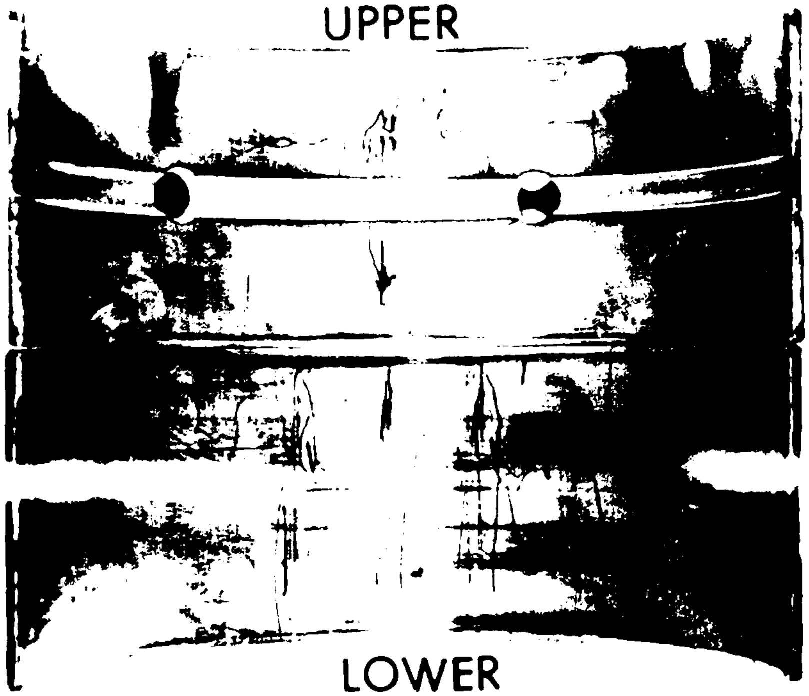
NHC - 250 TEST #2
FUEL EVALUATION
6


NHC - 250 TEST # 2
FUEL EVALUATION
2


NHC - 250 TEST # 2
FUEL EVALUATION
4

NHC-250 TEST #2
FUEL EVALUATION

THRUST 4 AN[illegible] HRUST


NHC -250 TEST #2
FUEL EVALUATION
MAIN BEARINGS
UPPER
LOWER
3


NHC -250 TEST #2
FUEL EVALUATION
ROD BEARINGS
UPPER
LOWER
5

APPENDIX G
Test Data and Photographs

LDT-465-1C Engine

210-Hour Test

Cat Fuel*

*Use of designation "Cat 1-H" test fuel refers to Reference No. 2 Diesel Fuel, or simply Cat Fuel.

LDT-465-1C
TEST 4
ENGINE REBUILD MEASUREMENTS

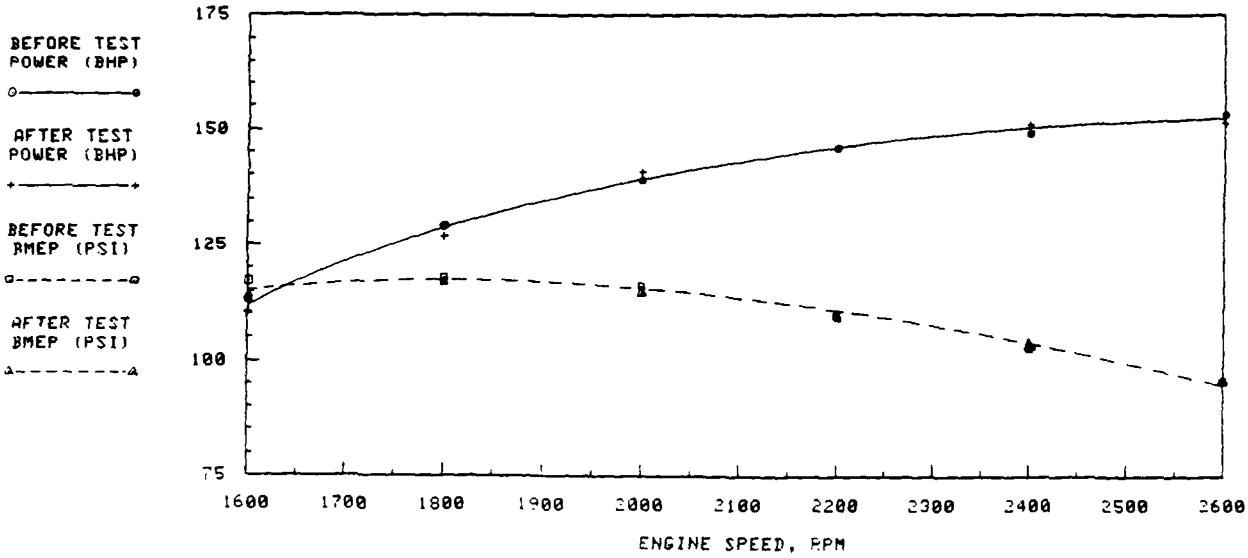
	Inches			
Cylinder Liners (Installed)	Min	Max	Avg	Specified Limits
Inside Diameter	4.5621	4.5644	4.5634	4.5630-4.5645
Out of Round	0.0002	0.0016	0.0010	0.0015 max
Piston Skirt Diameter (at bottom)	4.5554	4.5558	4.5556	4.5530-4.5580
No. 1 Ring				
End Gap	0.022	0.024	0.023	0.022-0.035
No. 2 Ring				
End Gap	0.021	0.025	0.023	0.022-0.035
No. 3 Ring				
End Gap	0.018	0.021	0.020	0.010-0.028
Side Clearance	0.002	0.002	0.002	0.0025-0.0045
No. 4 Ring				
End Gap	0.018	0.022	0.020	0.010-0.028
Side Clearance	0.0015	0.0015	0.0015	0.0010-0.0035

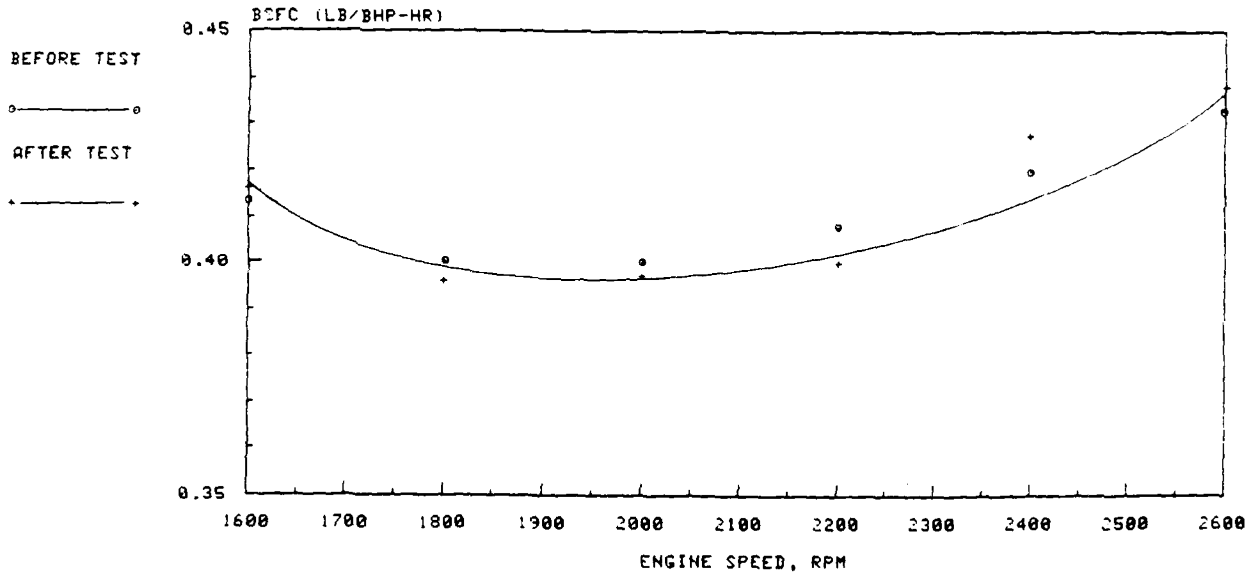
LDT-465-1C 210-HOUR WHEELED-VEHICLE CYCLE ENDURANCE TEST
TEST 4
OPERATING CONDITIONS SUMMARY
Fuel: AL-8764-F   Lubricant: AL-8980-L

	Power Mode			Idle Mode
	Min	Max	Avg	Avg
Engine Speed, rpm	2602	2614	2608	803
Torque, ft-lb (N-m)	308(418)	316(428)	311(422)	10(14)
Observed Power, Bhp (kW)	151(113)	158(118)	154(115)	1.5(1.1)
Fuel Consumption, lb/hr (kg/hr)	66.2(30.1)	67.3(30.6)	66.8(30.3)	7.1(3.2)
BSFC, lb/Bhp-hr (g/kW-hr)	0.422(268)	0.442(280)	0.433(275)	4.8(3046)
Temperatures, °F(°C)				
Exhaust before turbocharger	954(512)	978(526)	964(518)	292(144)
Water Jacket Inlet	168(76)	172(78)	170(77)	99(37)
Water Jacket Outlet	180(82)	182(83)	180(82)	104(40)
Oil Sump	229(109)	234(112)	232(111)	129(54)
Fuel In	91(33)	96(36)	93(34)	84(29)
Inlet Air	80(27)	92(33)	87(31)	81(27)
Intake Manifold	220(104)	238(114)	229(109)	85(29)
Pressures				
Intake Vacuum, in. H_2O (Pa)	2.6(650)	2.7(670)	2.7(670)	0.1(20)
Exhaust Common, in. Hg (kPa)	0.7(2.4)	0.9(3.1)	0.8(2.7)	0.0(0.0)
Intake Manifold, psi (kPa)	9.6(66.1)	10.2(70.3)	9.9(68.2)	0.0(0.0)
Exhaust Manifold, psi (kPa)	12.5(86.1)	13.0(89.6)	12.8(88.2)	1.0(6.9)
Fuel Transfer Pump, psi (kPa)	69(475)	70(482)	70(482)	38(262)
Oil Gallery, psi (kPa)	64(441)	68(469)	67(462)	76(524)
Blowby, in. H_2O (Pa)	0.6(140)	1.2(290)	0.8(200)	0.1(30)
Ambient Conditions				
Wet Bulb Temperature, °F(°C)			67(19)	
Dry Bulb Temperture, °F(°C)			75(24)	
Barometric Pressure, in. Hg (kPa)			29.08(98.6)	

LDT-465 210 HOUR WHEELED VEHICLE CYCLE

BEFORE AND AFTER TEST 4 PERFORMANCE DATA





LDT-465-1C
TEST 4
LUBRICANT ANALYSIS
Lubricant: AL-8980-L

	ASTM Test Method	0	70	140	210
Apparent Viscosity at -29°C(-20°F), cP	D 2602	>26500	>26500	>26500	>26500*
Apparent Viscosity at -18°C(0°F), cP	D 2602	>9670	>9670	>9670	>9670 *
Kinematic Viscosity at 40°C(104°F), cSt	D 445	110	199	292	297
Kinematic Viscosity at 100°C(212°F), cSt	D 445	11.6	17.7	22.4	23.2
Viscosity Index	D 2270	92	96	94	97
Total Acid Number, mg KOH/g	D 664	5.4	4.8	5.7	6.0
Total Base Number, mg KOH/g	D 664	13.1	5.4	5.1	5.5
Pentane B Insolubles, wt%	D 893	0.02	2.80	5.62	6.71
Toluene B Insolubles, wt%	D893	0.02	2.16	4.74	5.31
Flash Point, °C(°F)	D 92	214(417)	204(399)	222(432)	214(417)
Density at 16°C(60°F), g/ml	D 287	0.90	0.93	0.94	0.94
Carbon Residue, wt%	D 524	1.5	4.5	6.3	7.1
Sulfated Ash, wt%	D 874	1.8	2.4	3.2	3.6

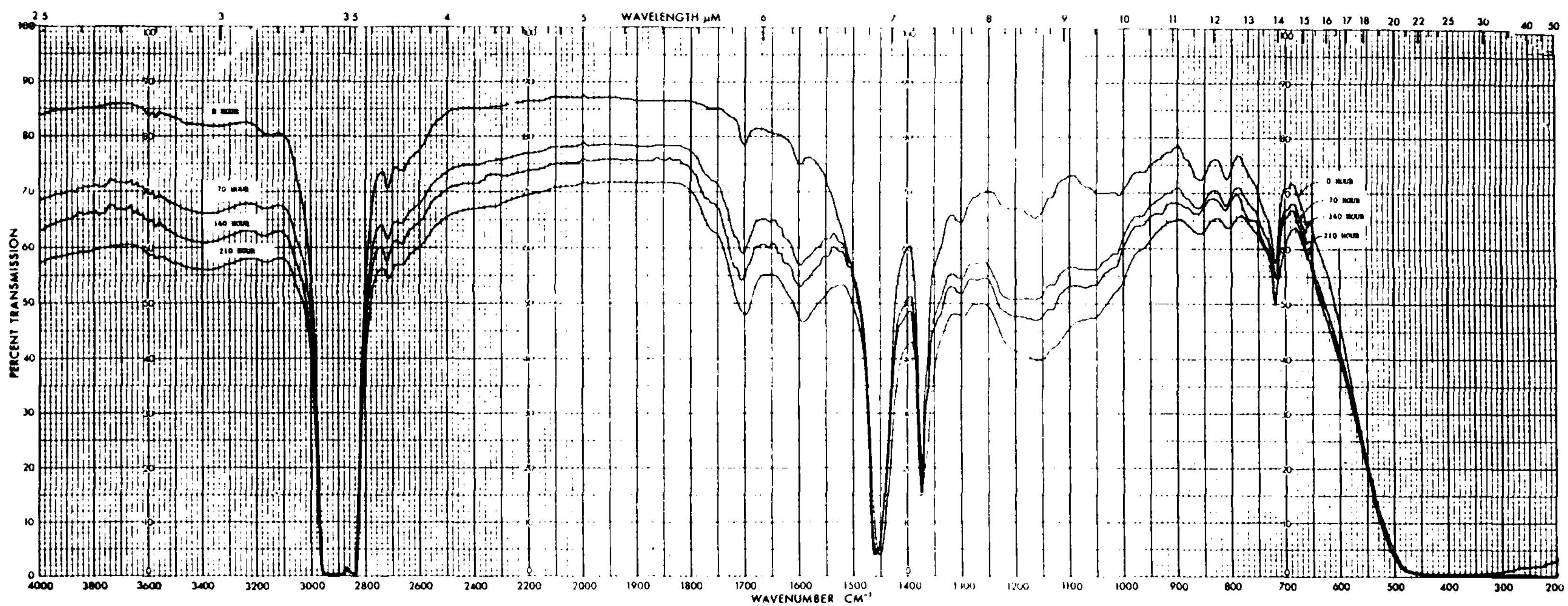
*The reason for unchanging viscosities with time is that the lubricant viscosity, at all test times, exceeded the limits of the viscosity standards currently available.

LDT-465-1C
TEST 4
TOTAL OIL CONSUMPTION AND WEAR METALS
Lubricant: AL-8980-L

Test Time, Hours	Total Oil Consumed, lb(kg)	Wear Metals+, ppm	
		Fe (Iron)	Cu (Copper)
14	6.8(3.1)	25	---*
28	19.0(8.6)	24	---
42	27.4(12.4)	34	19
56	38.2(17.3)	41	---
70	49.2(22.3)	52	---
84	59.2(26.9)	53	---
98	71.6(32.5)	62	---
112	79.2(35.9)	62	---
126	87.9(39.9)	74	13
140	99.6(45.2)	93	---
154	111.1(50.4)	84	10
168	123.9(56.2)	87	10
182	134.6(61.1)	98	8
196	145.4(66.0)	98	10
210	155.8(70.7)	108	---

Average Oil Consumption Rate: 0.74 lb/hr (0.34kg/hr)
+ No other wear metals detected.
* --- = Not Detected.

LDT-465-1C
TEST 4
Lubricant: AL-8980-L



LDT-465-1C
TEST 4
WEAR MEASUREMENTS
Lubricant: AL-8980-L

Cylinder Liner Bore Diameter, inches

	Before Test			After Test			Change		
	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
1 T-AT	4.5639	4.5642	4.5644	4.5650	4.5652	4.5653	0.0011	0.0010	0.0009
F-B	4.5629	4.5629	4.5629	4.5633	4.5630	4.5632	0.0004	0.0001	0.0003
2 T-AT	4.5692	4.5638	4.5636	4.5646	4.5642	4.5639	0.0004	0.0004	0.0003
F-B	4.5632	4.5634	4.5638	4.5637	4.5638	4.5640	0.0005	0.0004	0.0002
3 T-AT	4.5635	4.5636	4.5635	4.5642	4.5641	4.5641	0.0007	0.0005	0.0006
F-B	4.5625	4.5623	4.5625	4.5632	4.5617	4.5628	0.0007	-0.0006	0.0003
4 T-AT	4.5640	4.5641	4.5640	4.5645	4.5644	4.5643	0.0005	0.0003	0.0003
F-B	4.5622	4.5625	4.5632	4.5633	4.5633	4.5636	0.0011	0.0008	0.0004
5 T-AT	4.5635	4.5637	4.5638	4.5643	4.5642	4.5639	0.0008	0.0005	0.0001
F-B	4.5621	4.5623	4.5626	4.5631	4.5630	4.5632	0.0010	0.0007	0.0007
6 T-AT	4.5633	4.5640	4.5641	4.5644	4.5646	4.5645	0.0011	0.0006	0.0007
F-B	4.5628	4.5633	4.5637	4.5634	4.5636	4.5639	0.0006	0.0002	0.0002

Average Change, in.:+0.0005

LDT-465-1C
TEST 4
WEAR MEASUREMENTS
Lubricant: AL-8980-L

Piston Ring End Gap, inches

Piston No.	Ring No.	Before Test End Gap	After Test End Gap	Change
1	1	0.022	0.024	0.002
	2	0.021	0.024	0.003
	3	0.018	0.020	0.002
	4	0.020	0.024	0.004
2	1	0.022	0.025	0.003
	2	0.021	0.024	0.003
	3	0.019	0.020	0.001
	4	0.018	0.020	0.002
3	1	0.024	0.027	0.003
	2	0.023	0.024	0.001
	3	0.021	0.023	0.002
	4	0.022	Broke	---
4	1	0.023	0.025	0.002
	2	0.025	0.028	0.003
	3	0.020	0.022	0.002
	4	0.021	0.026	0.005
5	1	0.024	0.027	0.003
	2	0.023	0.025	0.002
	3	0.020	0.021	0.001
	4	0.022	0.024	0.002
6	1	0.023	0.025	0.002
	2	0.023	0.024	0.001
	3	0.020	0.021	0.001
	4	0.019	0.020	0.001

Average Change, in.: +0.002

POST TEST ENGINE CONDITION AND DEPOSITS
LDT-465-1C TEST 4
Engine SN: 3904343
Lubricant: AL-8980-L
Fuel: Cat 1-H
Date Started: 19 Dec 1979
Date Completed: 14 Jan 1980
Test: 210 Hour Wheeled Vehicle Cycle

A. CYLINDER RATINGS

		Cylinder Number					
		1		2		3	
Deposits		Carb	Lacq	Carb	Lacq	Carb	Lacq
Cylinder Head		10% AHC* 90% Soot	0	5% AHC 95% Soot	0	10% AHC 95% Soot	0
Cylinders	ART**	15% ½AHC 10% ¼AHC	10% 5[+]	15% ½AHC 5% ¼AHC	5% 5 5% 9	15% ½AHC	5% 5 5% 7 5% 9
	RTA	0	0	0	0	0	0
	BRT[1]	0	100% 7	0	100% 7	0	100% 7

		Cylinder Numbers					
		4		5		6	
Deposits		Carb	Lacq	Carb	Lacq	Carb	Lacq
Cylinder Head		10% AHC 90% Soot	0	5% AHC 95% Soot	0	5% AHC 95% Soot	0
Cylinders	ART**	10% ½AHC 20% ¼AHC	5% 5 5% 7 5% 8	10% ½AHC 20% ¼AHC	5% 4 5% 9	15% ½AHC 5% ¼AHC	5% 8
	RTA	0	0	0	0	0	0
	BRT[1]	0	100% 7	0	100% 7	0	100% 7

Surface Condition		1	2	3
Cylinders	RTA	5% G, LS[++]	LS	LS
	BRT	N	N	N

Surface Condition		4	5	6
Cylinders	RTA	5% G, LS	LS	LS
	BRT	N	N	N

* HC = Hard carbon, and the number-letter prefix indicates carbon depth with ¼A = least, through the alphabet to J = most.
** ART = Above ring travel, RTA = Ring travel area, BRT = Below ring travel.
\+ The higher the number, the darker the lacquer (0 = lightest, 9 = darkest).
++ V = Very, L = Light, H = Heavy, G = Glazing, P = Pitting, W = Wiping, F = Flaking, S = Scratched, T = Thrust side, AT = Anti-thrust side.
1 Accurate evaluation difficult due to the metal treatment given new cylinders.

B. PISTON RATINGS

Ring Face Condition	Cylinder Number 1	2	3	4	5	6
No. 1	N[a]	N	N	N	N	N
No. 2	N	N	N	N	N	N
No. 3	N	N	N	N	N	N
No. 4 (oil control)	N	N	–[c]	N	N	N
Oil Ring Slots, % Open	100	100	100	100	100	100

Ring Deposits

Piston Deposits		Cylinder Number 1		2		3	
		Carb	Lacq	Carb	Lacq	Carb	Lacq
Top	1	0	1% 5	0	1% 8	0	0
	2	0	0	0	1% 3	0	10% 3
	3	0	80% 5 20% 7	0	100% 7	0	75% 5 25% 7
ID	1	0	30% 3 55% 6 15% 8	50% AHC	15% 3 35% 9	45% AHC	35% 4 20% 9
	2	100% AHC	0	70% AHC 30% ½AHC	0	25% ½AHC	75% 9
	3	0	100% 9	0	100% 9	0	100% 9
Bottom	1	0	0	0	0	0	0
	2	0	5% 3	0	10% 3	0	5% 3
	3	0	100% 7	0	85% 6 15% 7	0	65% 5 35% 7

Piston Deposits		Cylinder Number 4		5		6	
		Carb	Lacq	Carb	Lacq	Carb	Lacq
Top	1	0	15% 5 2% 9	0	0	0	1% 5
	2	0	10% 4	0	0	0	0
	3	0	85% 5 15% 7	0	50% 4 50% 6	0	100% 6
ID	1	10% ½AHC 40% ¼AHC	50% 5	0	25% 3 15% 6 15% 7 45% 9	0	35% 4 65% 9
	2	40% ¼AHC	60% 9	100% ¼AHC	0	100% ¼AHC	0
	3	0	100% 9	0	100% 9	0	100% 9
Bottom	1	0	10% 5	0	0	0	0
	2	0	0	0	20% 3	0	0
	3	0	95% 6 5% 7	0	80% 4 20% 6	0	85% 4 15% 7

[a] N = Normal condition, no scuffing

[b] sc = Scuffed

[c] – = Ring broke while removing

Piston Surface Condition

	Piston Number 1	2	3	4	5	6
Top Ring Land	N	N	N	N	N	N
Skirt	N, LS	N, LS	N, LS	N, LS	N, LS	N, LS
Piston Pin	N	N	N	N	N	N

CRC Diesel Engine Piston Rating

	Piston Number 1	2	3	4	5	6
WTD[d] rating	289	195	288	312	316	241

Av. WTD rating: 274

C. VALVE RATINGS

	Cylinder Number 1		2		3		4		5		6	
	INT	EXH	INT	EXH	INT	EXH	INT	EXH	INT	EXH	INT	EXH
Freeness in Guide	F[e]	F	F	S[f]	F	S	F	S	F	S	F	F
Head	-All Normal-											
Face	-All Normal, Light Pitting-											
Seat	-All Normal, Light Pitting-											
Stem	N	LG[g]	N	LG	N	LG	N	LG	N	LG	N	LG
Tip	-All Normal-											

D. OTHER RATINGS

Bearing Surface Condition - All normal

---

[d] WTD = Weighted Total Deposits, 0 = Clean, 900 = maxinum possible deposits

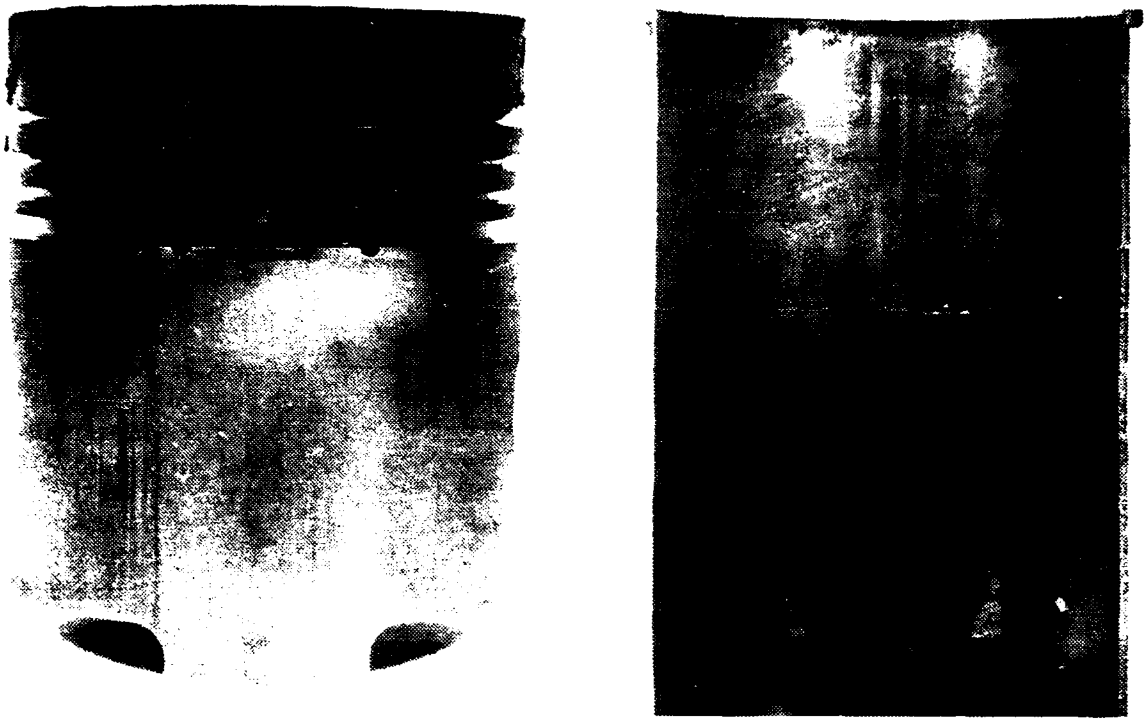
[e] F = Free

[f] S = Stuck (The stuck valves came loose with a light tap)

[g] LG = Light Gauling

LDT-465-1C
TEST 4
Lubricant: AL-8980-L

AFTER TEST CONDITION OF PISTON AND CYLINDER LINER

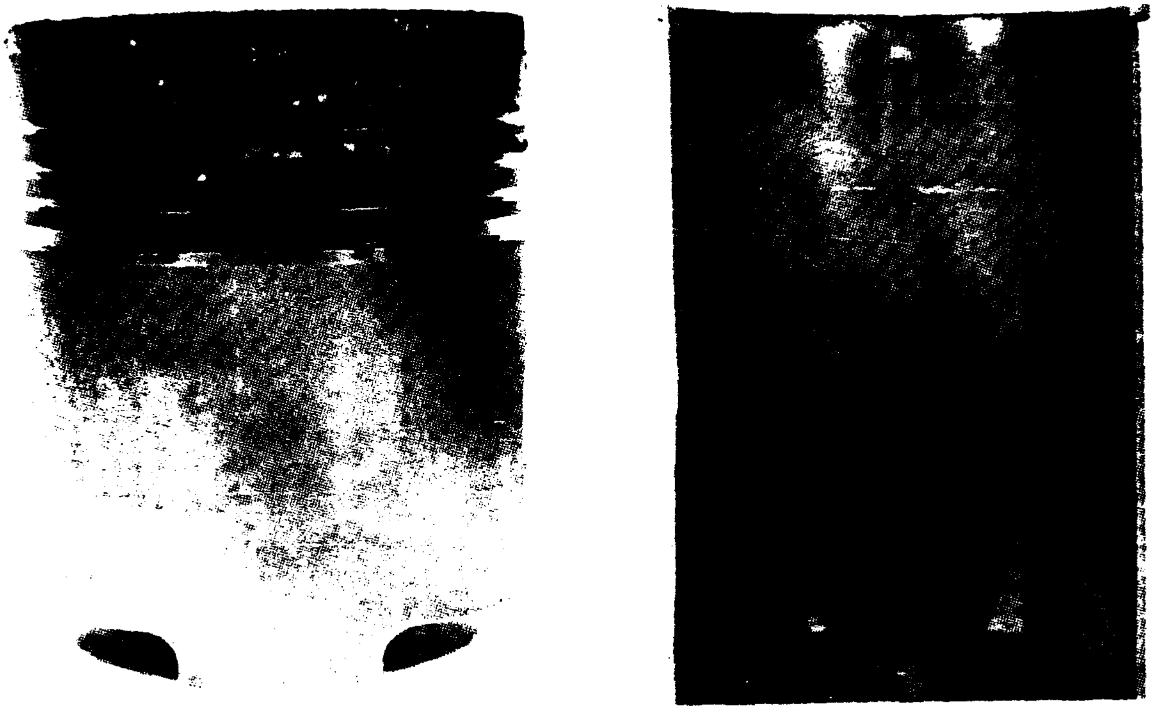


1 Anti-Thrust

1-Thrust

LDT-465-1C
TEST 4
Lubricant: AL-8980-L

AFTER TEST CONDITION OF PISTON AND CYLINDER LINER



2 Thrust*

2 Anti-Thrust*

* No. 2 Piston had the lowest Weighted Total [illegible]posit (WTD) rating.

LDT-465-1C
TEST 4
Lubricant: AL-8980-L

AFTER TEST CONDITION OF PISTON AND CYLINDER LINER

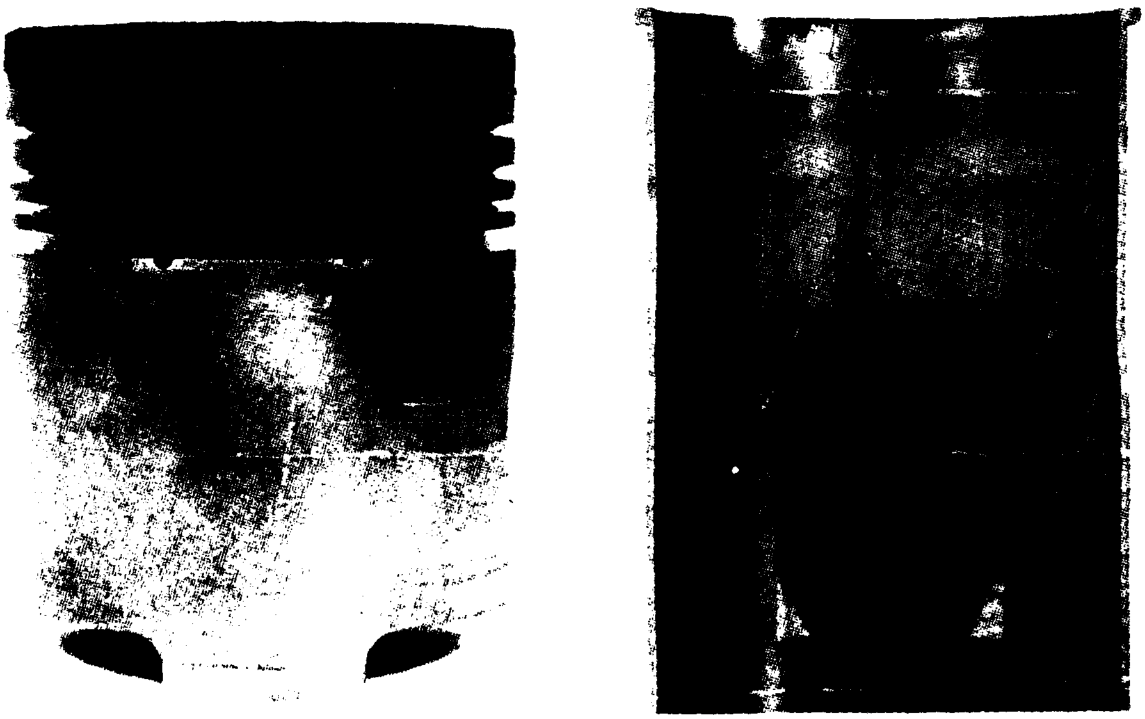
3 Thrust

3 Anti-Thrust

LDT-465-1C
TEST 4
Lubricant: AL-8980-L

AFTER TEST CONDITION OF PISTON AND CYLINDER LINER

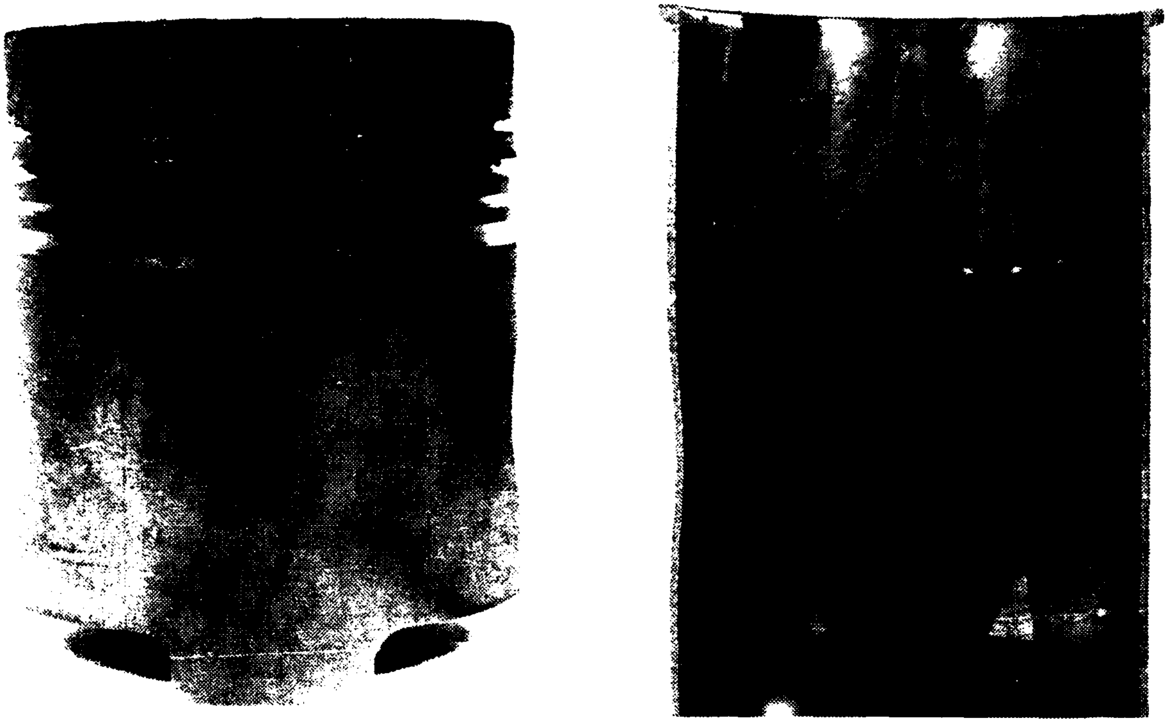
4 Thrust



4 Anti-Thrust

LDT-465-1C
TEST 4
Lubricant: AL-8980-L

AFTER TEST CONDITION OF PISTON AND CYLINDER LINER



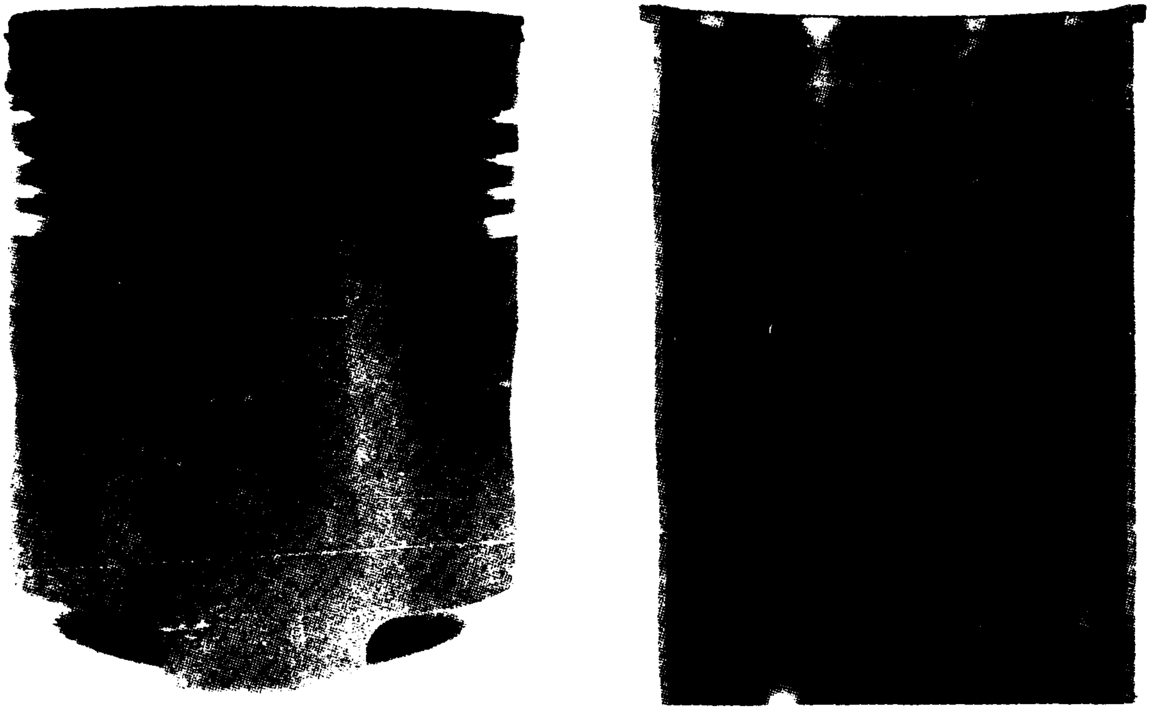
5 Thrust*

5 Anti-Thrust*

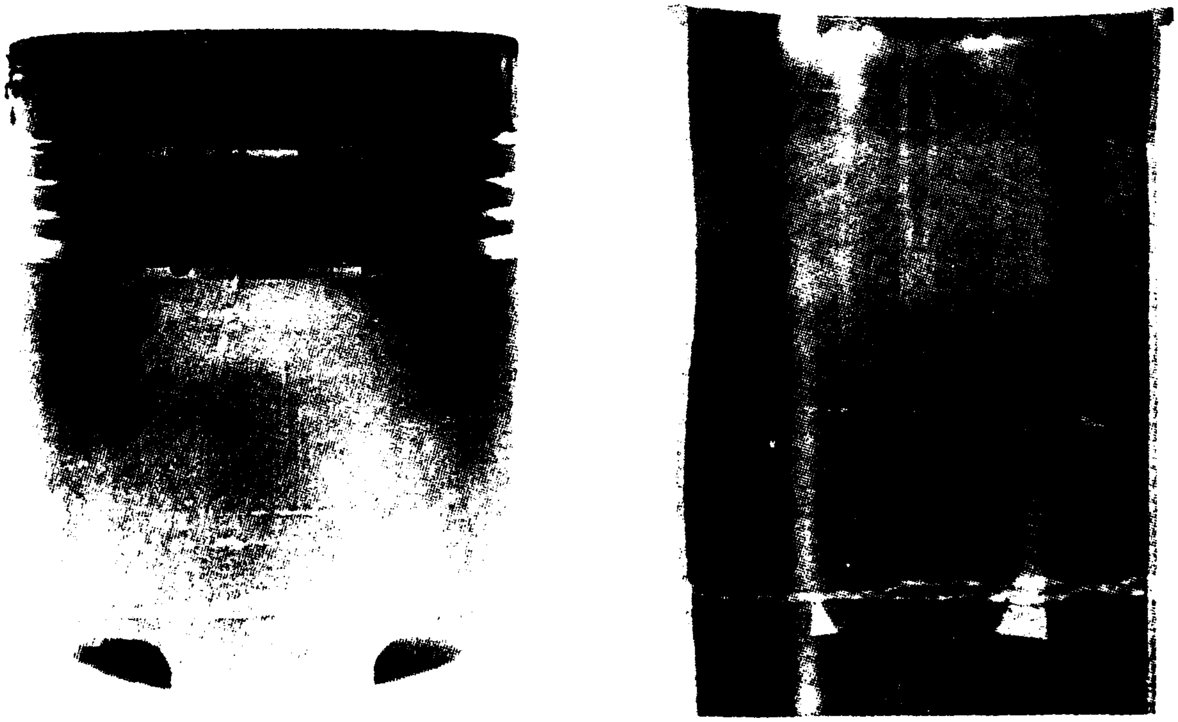
* No. 5 Piston had the highest Weighted Total Deposits (WTD) rating.

LDT-465-1C
TEST 4
Lubricant: AL-8980-L

AFTER TEST CONDITION OF PISTON AND CYLINDER LINER

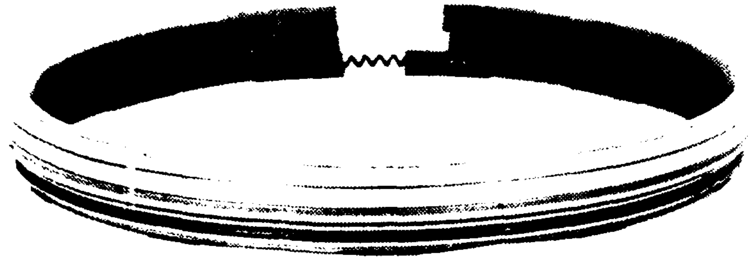


6 Thrust

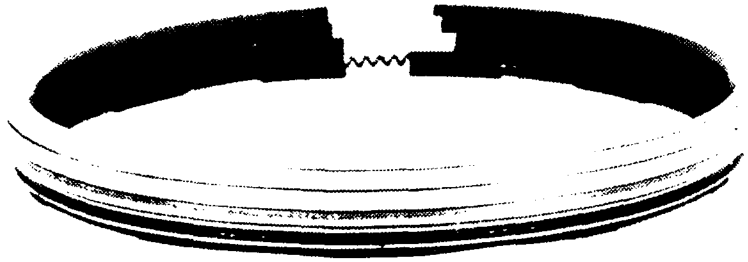


6 Anti-Thrust

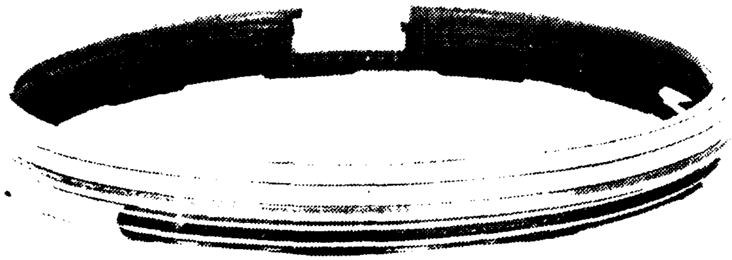
LDT-465-1C
TEST 4
Lubricant: AL-8980-L
AFTER TEST CONDITION OF PISTON RINGS



No. 1

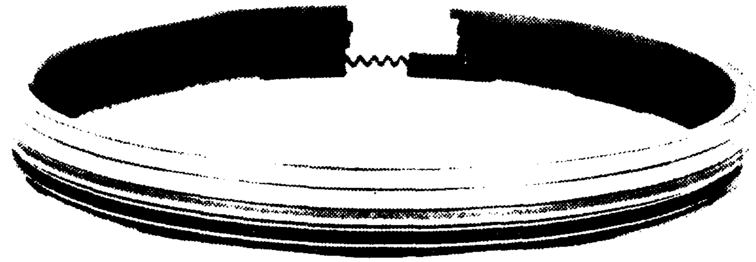


No. 2



No. 3

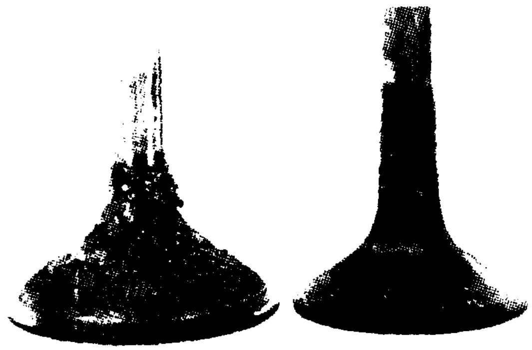
No. 4
(largest increase in end gap)



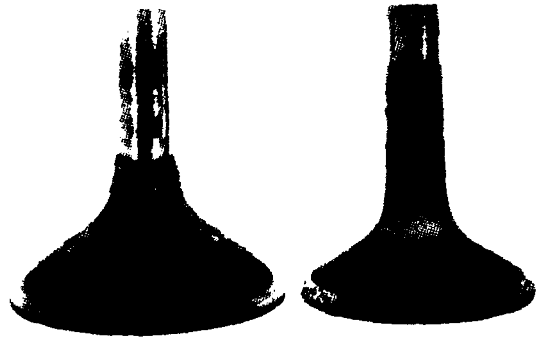
No. 5

No. 6
(least increase in end gap)

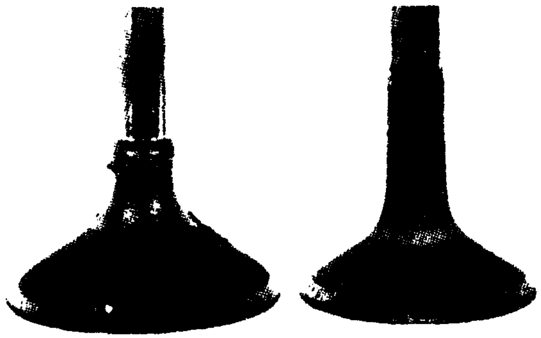
LDT-465-1C
TEST 4
Lubricant: AL-8980-L
AFTER TEST CONDITION OF INTAKE AND EXHAUST VALVES



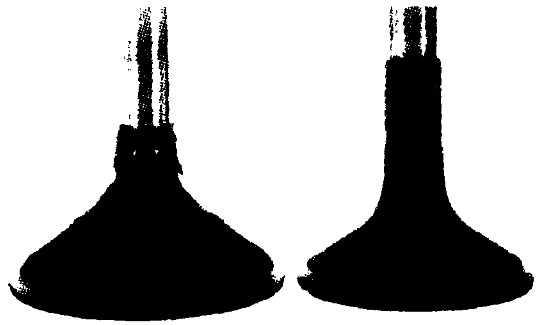
No. 1



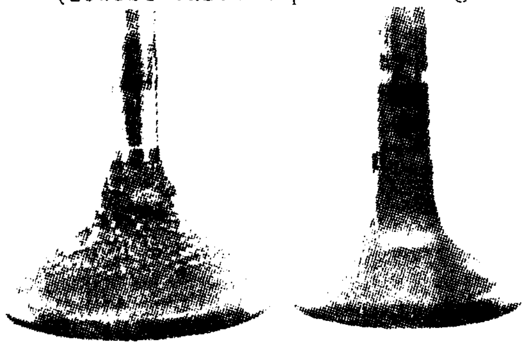
No. 4



No. 2
(lowest valve deposit rating)



No. 5

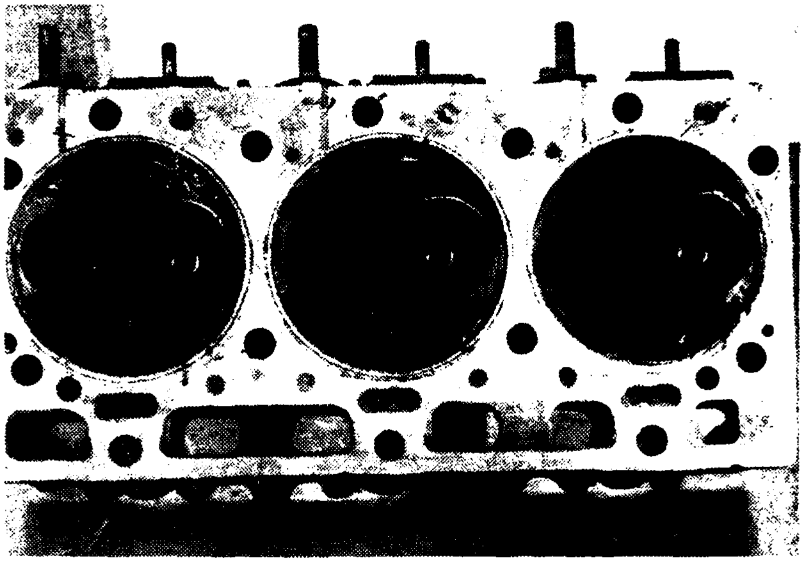


No. 3

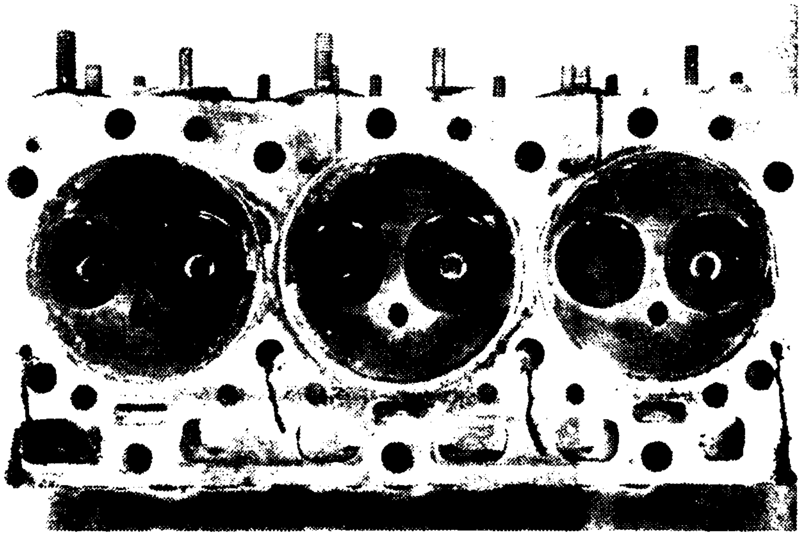
No. 6
(highest valve deposit rating)

LDT-465-1C
TEST 4
Lubricant: AL-8980-L

AFTER TEST CONDITION OF CYLINDER HEADS



Cylinders 3, 2, 1



Cylinders 6, 5, 4

APPENDIX H
Test Data and Photographs

LDT-465-1C Engine
210-Hour Test
JP-8 Fuel

LDT-465-1C
AFQP TEST 1
ENGINE REBUILD MEASUREMENTS

	Inches			
	Min	Max	Avg	Specified Limits
<u>Cylinder Liners (Installed)</u>				
Inside Diameter	4.5634	4.5652	4.5639	4.5630 - 4.5645
Out of Round	0.0010	0.0020	0.0010	0.0015 max
Piston Skirt Diameter (at bottom)	4.5576	4.5578	4.5577	4.5530 - 4.5580
<u>No. 1 Ring</u>				
End Gap	0.020	0.025	0.022	0.022 -0.035
<u>No. 2 Ring</u>				
End Gap	0.021	0.026	0.022	0.022 -0.035
<u>No. 3 Ring</u>				
End Gap	0.017	0.022	0.019	0.010 -0.028
Side Clearance	0.002	0.002	0.002	0.0025 - 0.0045
<u>No. 4 Ring</u>				
End Gap	0.015	0.019	0.017	0.010 -0.028
Side Clearance	0.002	0.002	0.002	0.0010 - 0.0035

LDT-465 ENGINE
OPERATING CONDITION SUMMARY
Lubricant: AL-14248-L
JP-8 Fuel: AL-14216-F

	Full Power Mode (2600 rpm)		Idle Mode (800 rpm)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed (rpm)	2600	1.02	788	4.19
Torque (ft-lb)	301.64	5.03	14.92	0.54
Fuel Consumption (lb/hr)	64.36	0.84	4.04	0.15
Observed Power (Bhp)	149.32	2.47	2.19	0.08
BSFC (lb/Bhp-hr)	0.431	0.005	1.856	0.064
Oil Gallery Pressure (psi)	59.85	0.64	51.41	0.42
Temperatures (°F)				
Water Jacket Inlet	166.29	1.65	90.80	0.58
Water Jacket Outlet	180.22	0.79	99.33	0.54
Oil Sump	233.90	1.84	114.07	3.20
Fuel Inlet	85.97	4.78	79.63	2.13
Air Inlet	87.12	8.67	78.00	7.77
Exhaust Temperatures (°F)				
Cylinder 1	962.82	16.07	206.22	9.79
Cylinder 2	1044.27	18.88	221.55	7.42
Cylinder 3	1052.59	19.52	217.67	6.31
Cylinder 4	1019.63	16.58	223.22	4.15
Cylinder 5	1006.59	17.20	222.72	7.85
Cylinder 6	971.69	17.07	242.93	7.49
Common	910.83	15.80	223.85	11.82

LDT-465-1C
AFQP TEST 1
WEAR MEASUREMENTS
Lubricant: AL-14248-L

Cylinder Liner Bore Diameter, Inches

	Before Test			After Test			Change		
	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
1 T-AT	4.5643	4.5648	4.5648	4.5647	4.5653	4.5651	+0.0004	+0.0005	+0.0003
F-B	4.5639	4.5638	4.5638	4.5638	4.5634	4.5638	-0.0001	-0.0004	0
2 T-AT	4.5638	4.5644	4.5644	4.5640	4.5643	4.5642	+0.0002	-0.0001	-0.0002
F-B	4.5641	4.5640	4.5636	4.5645	4.5639	4.5635	+0.0004	-0.0001	-0.0001
3 T-AT	4.5643	4.5654	4.5654	4.5643	4.5650	4.5657	0	-0.0004	+0.0003
F-B	4.5649	4.5643	4.5638	4.5655	4.5648	4.5637	+0.0006	+0.0005	-0.0001
4 T-AT	4.5645	4.5647	4.5641	4.5651	4.5650	4.5640	+0.0006	+0.0003	-0.0001
F-B	4.5641	4.5643	4.5644	4.5640	4.5641	4.5646	-0.0001	-0.0002	+0.0002
5 T-AT	4.5643	4.5651	4.5646	4.5647	4.5654	4.5649	+0.0004	+0.0003	+0.0003
F-B	4.5645	4.5643	4.5643	4.5650	4.5646	4.5646	+0.0005	+0.0003	+0.0003
6 T-AT	4.5644	4.5643	4.5643	4.5644	4.5641	4.5640	0	-0.0002	-0.0003
F-B	4.5639	4.5645	4.5642	4.5646	4.5650	4.5648	+0.0007	+0.0005	+0.0006

Average Change, in.: +0.0003

LDT-465-1C
AFQP TEST 1
LUBRICANT ANALYSIS
Lubricant: AL-14248-L

	ASTM Test Method	0	70	140	210
Kinematic Viscosity at 40°C (104°F), cSt	D 445	99.10	113.89	129.95	145.99
Kinematic Viscosity at 100°C (212°F), cSt	D 445	11.28	12.46	13.93	15.63
Viscosity Index	D 2270	99	100	104	111
Total Acid Number, mg KOH/g	D 664	2.96	4.96	4.87	4.16
Total Base Number, mg KOH/g	D 664	7.83	7.71	5.28	5.48
Pentane B Insolubles, wt%	D 893	---	0.31	1.23	0.35
Toluene B Insolubles, wt%	D 893	---	0.26	0.98	0.28
Flash Point, °F	D 92	---	450	445	460
Density at 16°C (60°F), g/mL	D 287	---	0.8982	0.9031	0.9090
Carbon Residue, wt%	D 524	---	2.03	2.48	2.77

LDT-465-1C
AFQP TEST 1
TOTAL OIL CONSUMPTION AND WEAR METALS
Lubricant: AL-14248-L

Test Time, Hours	Total Oil Consumed, lb (kg)	Wear Metals+, ppm Fe (Iron)	Cu (Copper)
0	0.0	33	---
14	0.0	19	---
28	0.45 (0.99)	39	---
42	1.58 (0.71)	44	---
56	3.92 (1.76)	59	---
70	5.29 (2.38)	69	---
84	8.75 (3.94)	74	---
98	10.16 (4.57)	76	10
112	12.69 (5.71)	92	10
126	14.79 (6.65)	91	13
140	17.36 (7.81)	96	---
154	19.06 (8.58)	98	---
168	22.33 (10.05)	97	---
182	24.90 (11.21)	107	---
196	27.30 (12.29)	104	---
210	28.65 (12.89)	135	13

Average Oil Consumption Rate: 0.14 lb/hr (0.06 kg/hr)
+ No other wear metals detected. Uncorrected for oil loss and make-up oil additions.
* ---- = Not Detected.

POST TEST ENGINE CONDITION AND DEPOSITS
AFQP LDT-465-1C TEST 1

Engine SN: 3904343
Lubricant: AL-14248-L
Fuel: JP-8 AL-14216-L
Test: 210-Hour Wheeled Vehicle Cycle

A. CYLINDER RATINGS

		Cylinder Number					
		1		2		3	
		Carb	Lacq	Carb	Lacq	Carb	Lacq
Deposits							
Cylinder Head		50% ½AHC* 50% ¼AHC	0	100% ½AHC	0	70% ½AHC 30% ¼AHC	0
Cylinders	ART**	80% AHC	5-6+	90% AHC	0	75% AHC	0
	RTA	++	++	++	++	++	++
	BRT	0	0	0	0	0	0

		Cylinder Number					
		4		5		6	
		Carb	Lacq	Carb	Lacq	Carb	Lacq
Deposits							
Cylinder Head		10% AHC 90% ½AHC	0	25% AHC 75% ½AHC	0	10% BHC 90% ½AHC	0
Cylinders	ART**	55% AHC 10% ¼AHC	5-9	75% AHC	0	85% AHC	0
	RTA	++	++	++	++	++	++
	BRT	0	0	0	0	0	0

Surface Condition		1	2	3
Cylinders	RTA	N+++	N	N
	BRT	N	N	N

Surface Condition		4	5	6
Cylinders	RTA	N	N	N
	BRT	N	N	N

* HC = Hard carbon, and the number-letter prefix indicates carbon depth with ¼A = least, through the alphabet to J = most.
** ART = Above ring travel, RTA = Ring travel area, BRT = Below ring travel.
\+ The higher the number, the darker the lacquer (0 = lightest, 9 = darkest).
++ Rust-like appearance.
+++ V = Very, L = Light, H = Heavy, G = Glazing, N = Normal Condition, No Scuffing, P = Pitting, W = Wiping, F = Flaking, S = Scratched, T = Thrust Side, AT = Anti-thrust Side.

B. PISTON RATINGS

	Cylinder Number					
	1	2	3	4	5	6
Ring Face Condition						
No. 1	N[a]	N	N	16.25	N	8.75
No. 2	N	N	N	8.75	N	7.50
No. 3	N	23.75	56.25	56.25	26.25	21.25
No. 4 (oil control)	N	N	_[b]	N	N	N
Oil Ring Slots, % Open	100	100	100	100	100	100

Ring Deposits

		Cylinder Number					
		1		2		3	
		Carb	Lacq	Carb	Lacq	Carb	Lacq
Piston Deposits							
Top	1	15% ½AHC		10% ½AHC	15% 4	0	90% 9
	2	0	20% 3	0	35% 6	0	15% 3
	3	40% AHC	20% 9	30% ¼AHC	55% 8	35% ¼AHC	10% 2
ID	1	100% ½AHC	0	100% ½AHC	0	100% ½AHC	0
	2	100% ¼AHC	0	100% ¼AHC	0	100% ¼AHC	0
	3	100% ¼AHC	0	0	0	50% ¼AHC	0
Bottom	1	0	30% 3	5% ¼AHC	30% 6	0	40% 7
	2	0	15% 2	0	20% 4	0	20% 3
	3	0	35% 9	0	32% 7	5% ¼AHC	20% 4

		Cylinder Number					
		4		5		6	
		Carb	Lacq	Carb	Lacq	Carb	Lacq
Piston Deposits							
Top	1	80% ¼A	0	35% AHC	10% 5	45% ¼A	0
	2	10% ½AHC	0	0	5% 3	0	40% 4
	3	50% ¼AHC	20% 7	0	80% 9	55% ½AHC	25% 9
ID	1	100% ¼AHC	0	50% ½AHC	0	100% ½AHC	0
	2	100% ¼AHC	0	100% ¼AHC	0	100% ¼AHC	0
	3	100% ¼AHC	0	100% ¼AHC	0	100% ¼AHC	0
Bottom	1	25% A	0	0	10% A	15% A	0
	2	60% ¼A	0	0	0	0	50% 4
	3	0	25% 7	0	35% 7	0	30% 4

[a]N = Normal Condition, No Scuffing.
[b]_ = Ring broke while removing.

Piston Surface Condition

	Piston Number					
	1	2	3	4	5	6
Top Ring Land	N	N	N	N	N	N
Skirt	N	N	N	N	N	N
Piston Pin	N	N	N	N	N	N

CRC Diesel Engine Piston Rating

	Piston Number					
	1	2	3	4	5	6
WTD[c] Rating	192	189	155	202	180	158
Av. WDT Rating: 179						

C. VALVE RATINGS

	Cylinder Number											
	1		2		3		4		5		6	
	INT	EXH	INT	EXH	INT	EXH	INT	EXH	INT	EXH	INT	EXH
Freeness in Guide	F[d]	F	F	S[e]	F	S	F	S	F	S	F	F
Head	All Normal											
Face	All Normal											
Seat	All Normal											
Stem	All Normal											
Tip	All Normal											

D. OTHER RATINGS

Bearing Surface Condition - All normal

---

[c]WTD = Weighted Total Deposits, 0 = Clean, 900 = maximum possible deposits.
[d]F = Free.
[e]S = Stuck (The stuck valves come loose with a light tap).

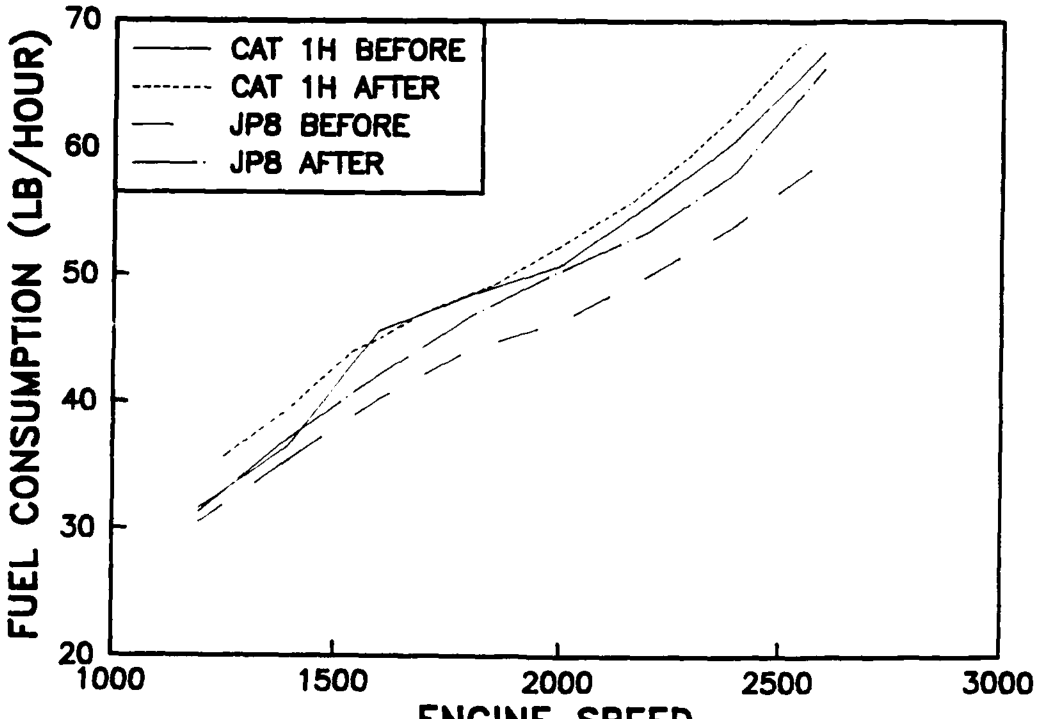
LDT-465-1C
TEST 4
WEAR MEASUREMENTS
Lubricant: AL-8980-L

Piston Ring End Gap, inches

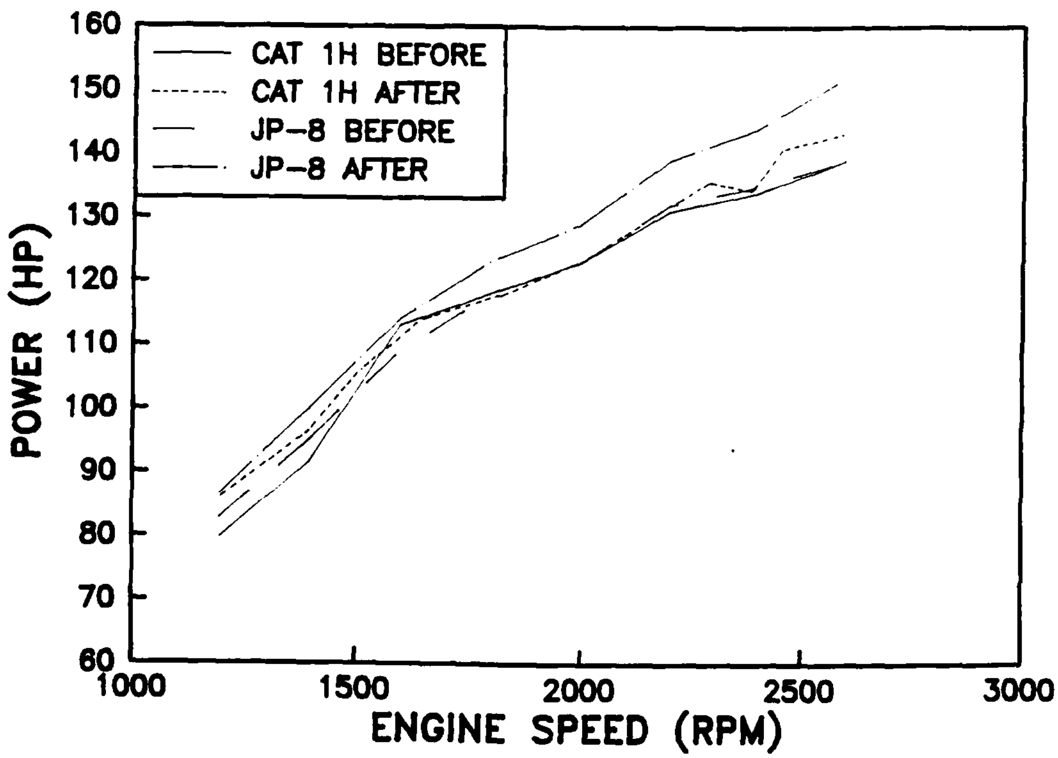
Piston No.	Ring No.	Before Test End Gap	After Test End Gap	Change
1	1	0.020	0.023	+0.003
	2	0.021	0.022	-0.001
	3	0.017	0.017	0.000
	4	0.015	0.015	0.000
2	1	0.022	0.025	+0.003
	2	0.021	0.023	+0.002
	3	0.018	0.018	0.000
	4	0.015	0.015	0.000
3	1	0.021	0.021	0.000
	2	0.022	0.022	0.000
	3	0.019	0.021	+0.002
	4	0.017	0.017	0.000
4	1	0.023	0.023	0.000
	2	0.021	0.021	0.000
	3	0.022	0.020	-0.002
	4	0.019	0.020	+0.001
5	1	0.025	0.025	0.000
	2	0.023	0.024	+0.001
	3	0.021	0.021	0.000
	4	0.019	0.019	0.000
6	1	0.022	0.022	0.000
	2	0.026	0.026	0.000
	3	0.020	0.020	0.000
	4	0.015	0.016	+0.001

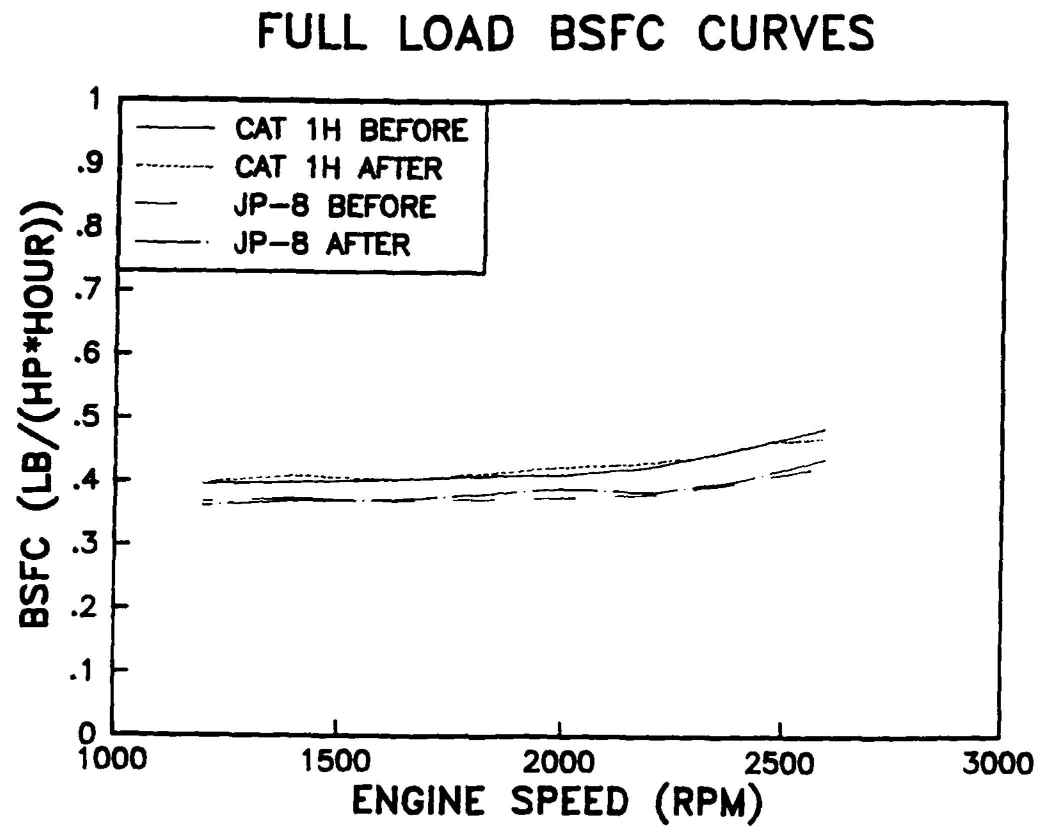
Average Change, in.: +0.002

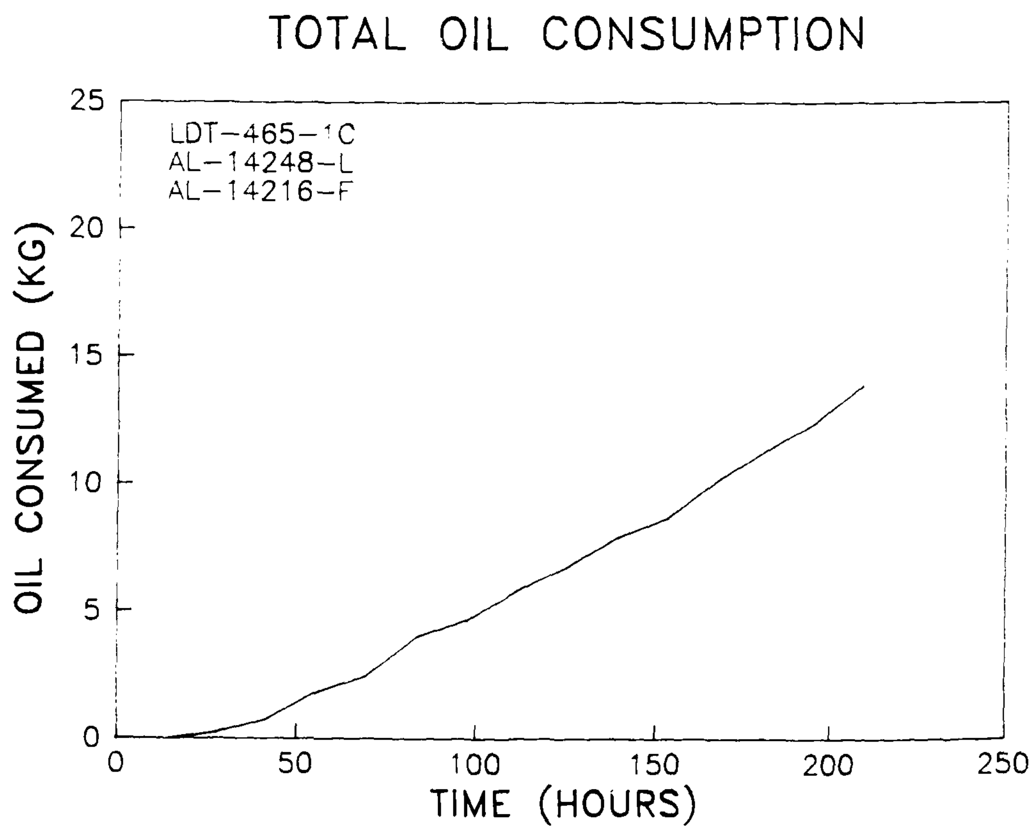
FULL LOAD FUEL CONSUMPTION



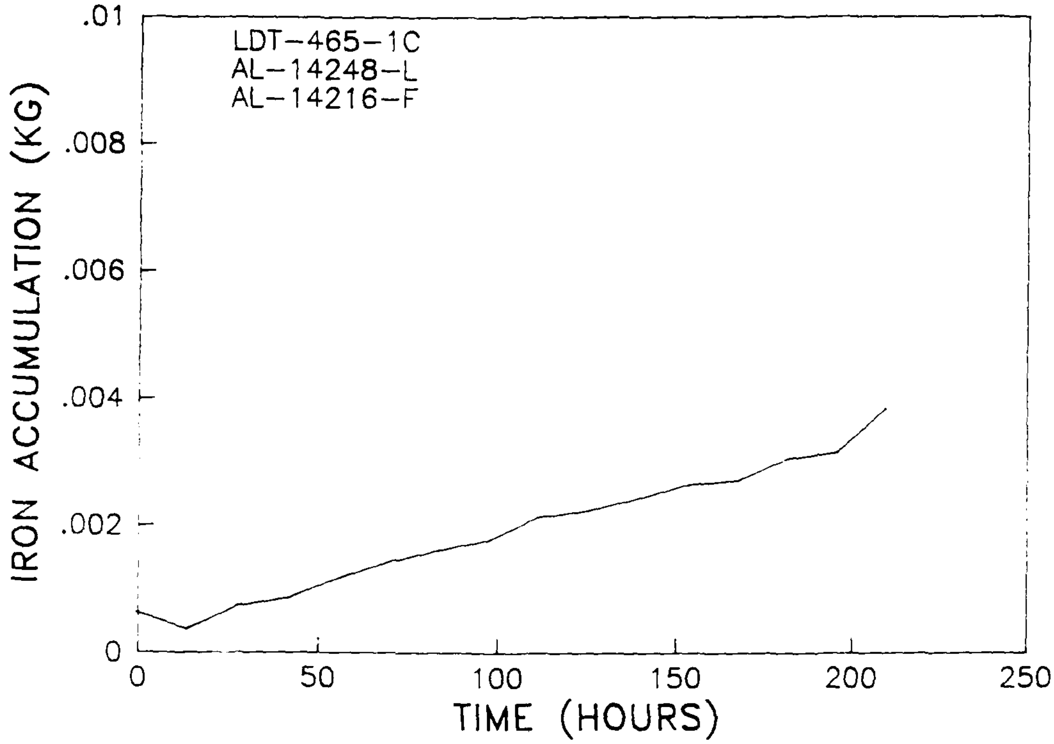
FULL LOAD POWER CURVES




FULL LOAD BSFC CURVES
CAT 1H BEFORE
CAT 1H AFTER
JP-8 BEFORE
JP-8 AFTER
BSFC (LB/(HP*HOUR))
ENGINE SPEED (RPM)

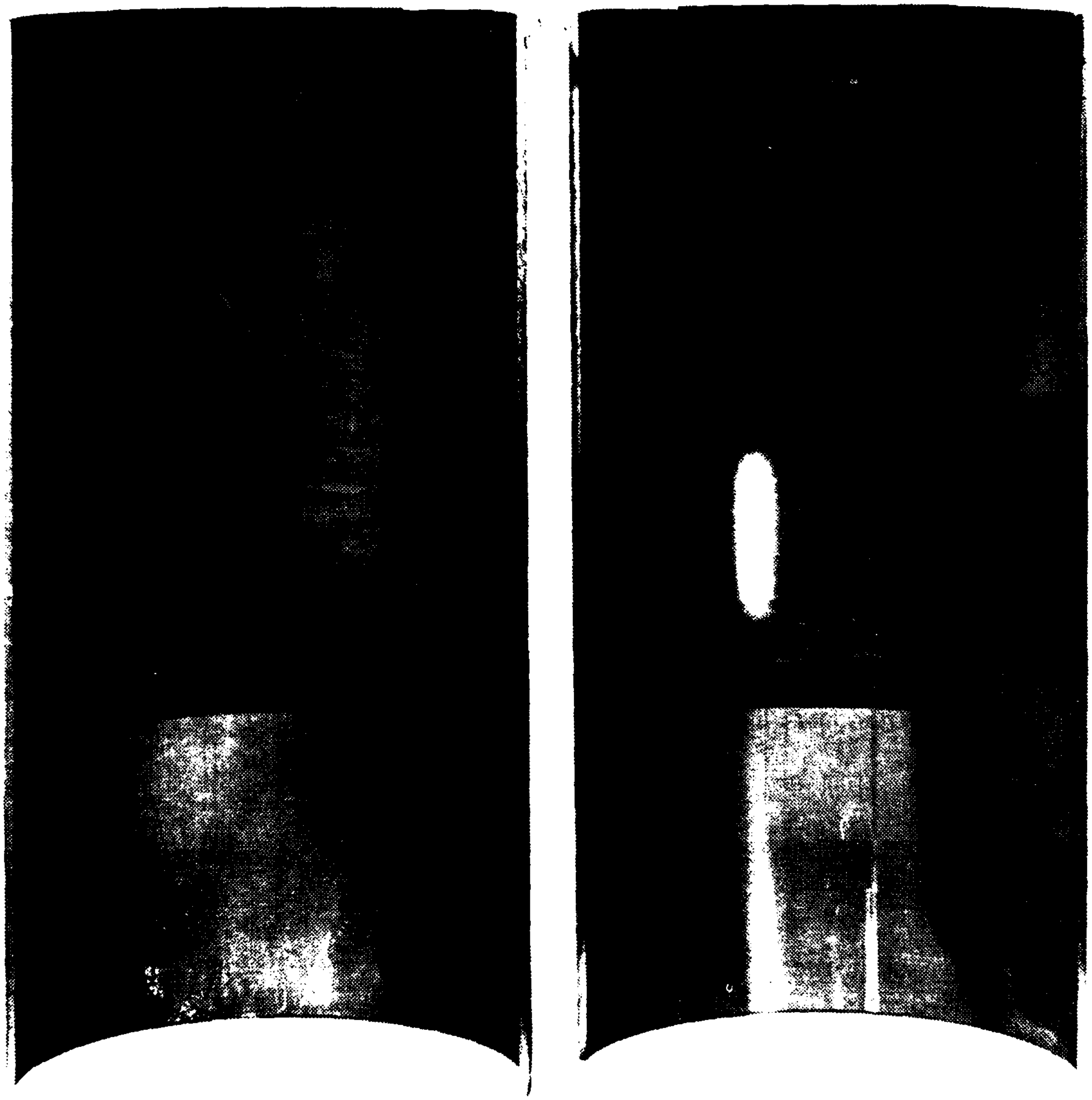

TOTAL OIL CONSUMPTION
LDT-465-1C
AL-14248-L
AL-14216-F
OIL CONSUMED (KG)
TIME (HOURS)

TOTAL IRON ACCUMULATION

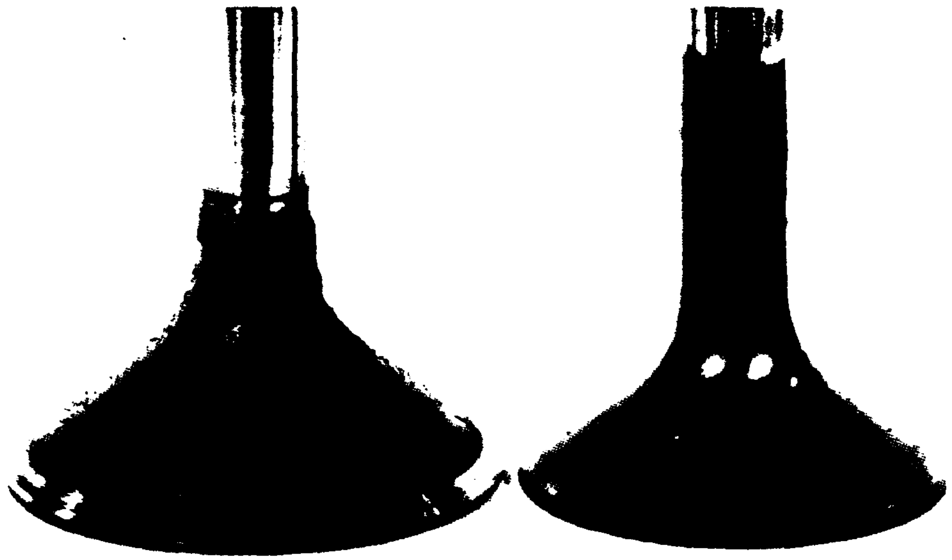


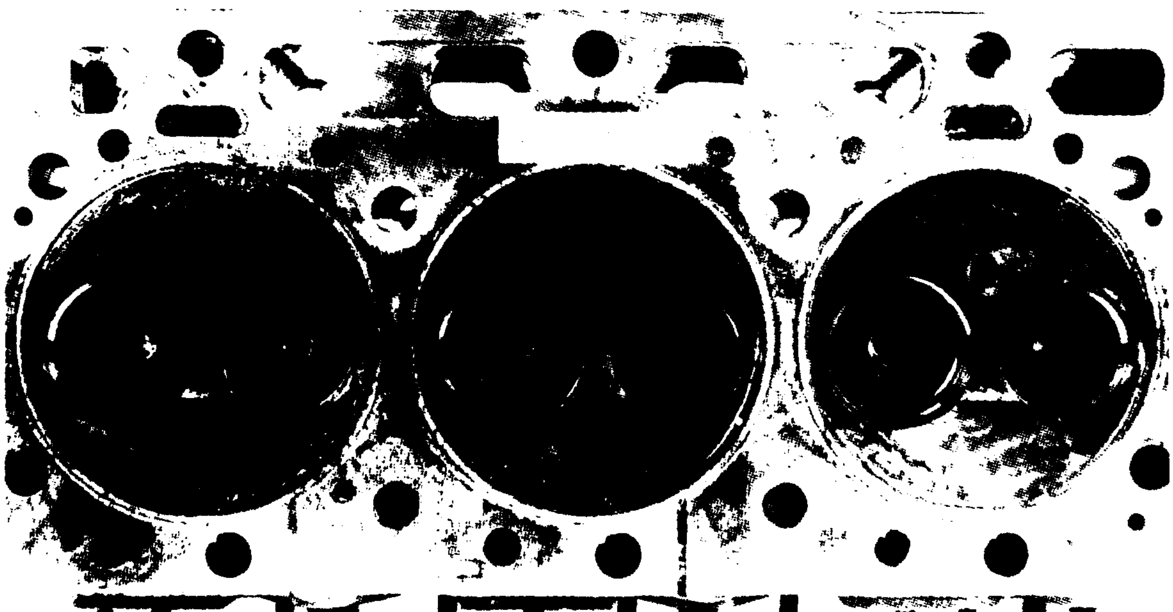
AFQP
LTD-465-1C-1
4

AFQP
LTD -465-1C -1
THRUST 6 ANTI - THRUST



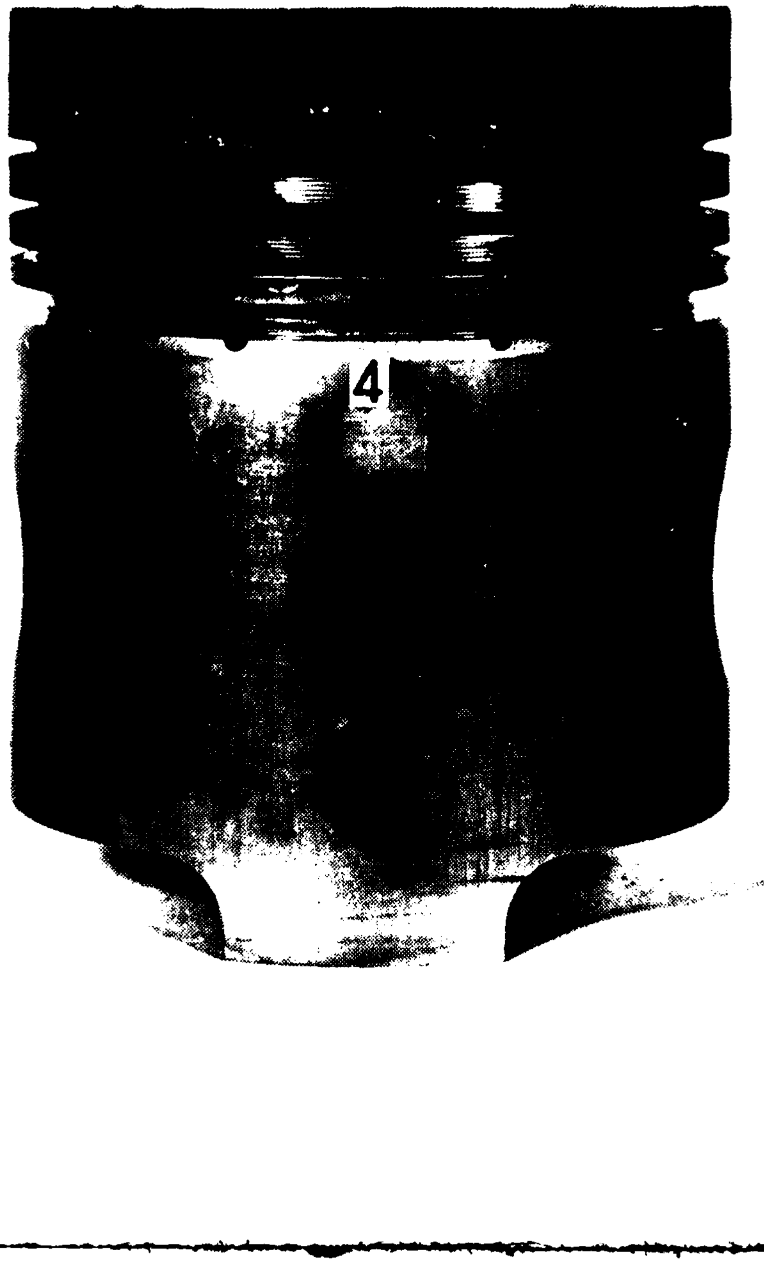
AFQP
LTD-465-1C-1
5



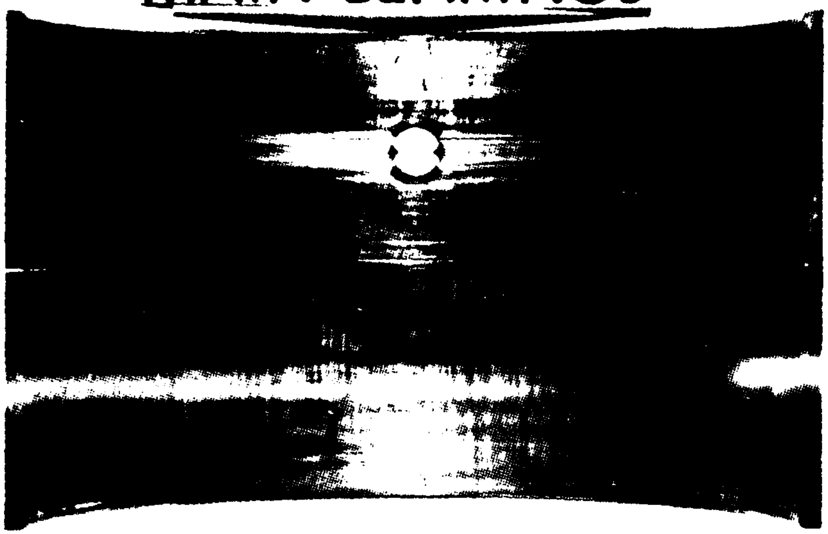


AFQP
LTD-465-1C-1
(T)

AFQP
LTD-465-1C-1
(AT)

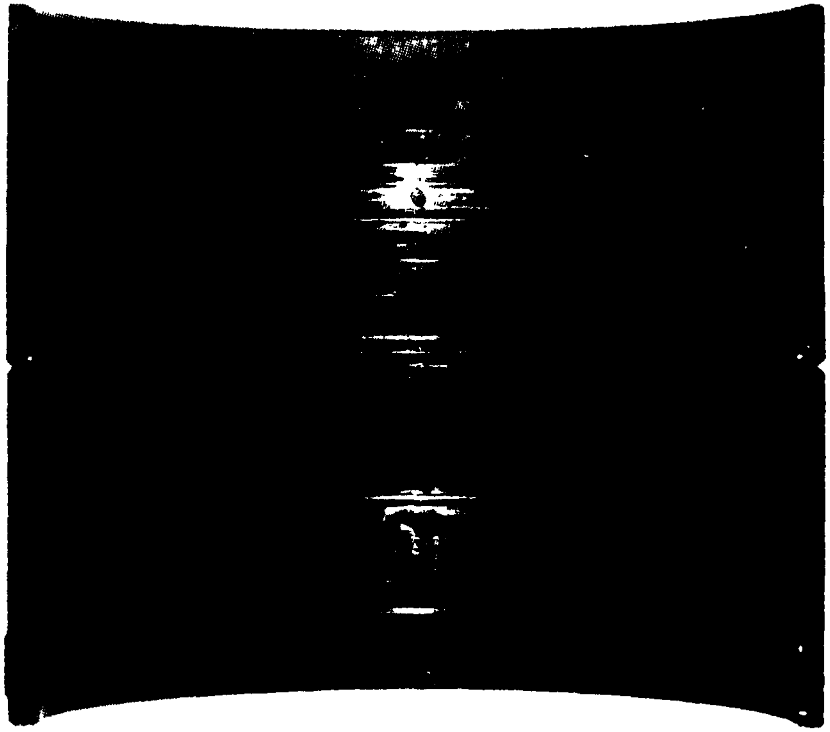


AFQP
LTD-465-1C-1
MAIN BEARINGS



1

AFQP
LTD-465-1C-1
ROD BEARINGS



1

APPENDIX I

Test Data and Photographs

DD 6V-53T Engine

240-Hour Test

Cat Fuel*

*Use of designation "Cat 1-H" test fuel refers to Reference No. 2 Diesel Fuel, or simply Cat Fuel.

6V-53T
TEST 37
ENGINE REBUILD MEASUREMENTS*
Model Number: 5063-5395
Serial Number: 6D-178671

	Min	Max	Avg	Specified Limits	
Cylinder Block Bore					
Inside Diameter (Bottom)	4.3577 (110.686)	4.3587 (110.711)	4.3580 (110.693)	4.3565 (110.655)	- 4.3575 (110.681) New
					- 4.3595 (110.731) Max
Out-of-Round	0.0000	0.0010 (0.025)	0.0006 (0.015)		- 0.0015 (0.038) Max
Taper	0.0000	0.0011 (0.028)	0.0004 (0.010)		- 0.0015 (0.038) Max
Cylinder Liners (Installed)					
Inside Diameter	3.8756 (98.440)	3.8766 (98.466)	3.8760 (98.450)	3.8752 (98.430)	- 3.8767 (98.468)
Out-of-Round	0.0000	0.0005 (0.013)	0.0002 (0.005)		- 0.0015 (0.038) Max
Taper	0.0000	0.0007 (0.018)	0.0004 (0.010)		- 0.0015 (0.038) Max
Piston Diameter (at skirt)	3.8669 (98.219)	3.8690 (98.273)	3.8683 (98.255)	3.8669 (98.219)	- 3.8691 (98.775)
Piston Skirt to Cylinder Liner Clearance	0.0070 (0.178)	0.0094 (0.239)	0.0079 (0.201)	0.0061 (0.155)	- 0.0098 (0.249)
Compression Rings					
Gap (No. 1, Fire Ring)	0.032 (0.81)	0.036 (0.91)	0.034 (0.86)	0.020 (0.51)	- 0.046 (1.17)
Gap (Nos. 2, 3, 4)	0.030 (0.76)	0.036 (0.91)	0.0[illegible] (0.84)	0.020 (0.51)	- 0.036 (0.91)
Ring-to-Groove Clearance					
Top (No. 1, Fire Ring)	0.003 (0.08)	0.004 (0.10)	0.004 (0.10)	0.003 (0.08)	- 0.006 (0.15)
No. 2, Compression Ring	0.007 (0.18)	0.008 (0.20)	0.008 (0.20)	0.007 (0.18)	- 0.010 (0.25)
No. 3 and 4, Compression Rings	0.006 (0.15)	0.006 (0.15)	0.006 (0.15)	0.005 (0.13)	- 0.008 (0.20)
Oil Control Rings, Nos. 5, 6, 7					
Gap	0.016 (0.41)	0.020 (0.51)	0.018 (0.46)	0.010 (0.25)	- 0.025 (0.64)
Ring-to-Groove Clearance	0.002 (0.05)	0.003 (0.08)	0.003 (0.08)	0.0015 (0.038)	- 0.0055 (0.140)
Piston Pin					
Pin-to-Piston Bushing Clearance	0.0030 (0.076)	0.0034 (0.086)	0.0032 (0.081)	0.0025 (0.064)	- 0.0034 (0.086)
Pin-to-Connecting Rod Bushing Clearance	0.0015 (0.038)	0.0019 (0.048)	0.0017 (0.043)	0.0010 (0.025)	- 0.0019 (0.048)
Connecting Rod Bearing-to-Journal Clearance	0.0019 (0.048)	0.0028 (0.071)	0.0023 (0.058)	0.0011 (0.028)	- 0.0041 (0.104)
Main Bearing-to-Journal Clearance	0.0040 (0.102)	0.0045 (0.114)	0.0043 (0.109)	0.0010 (0.025)	- 0.0040 (0.102)
Camshaft Bearing-to-Journal Clearance	0.0052 (0.132)	0.0054 (0.137)	0.0053 (0.135)	0.0045 (0.114)	- 0.0060 (0.152)

* Measurements are in inches and (mm). All rebuild measurements include kit 2R from 40-240 hours and omit the cylinder ring kit 2R which was changed out at 40 test hours.

6V-53T
240-HOUR TRACKED VEHICLE CYCLE ENDURANCE TEST
TEST 37
OPERATING CONDITIONS SUMMARY

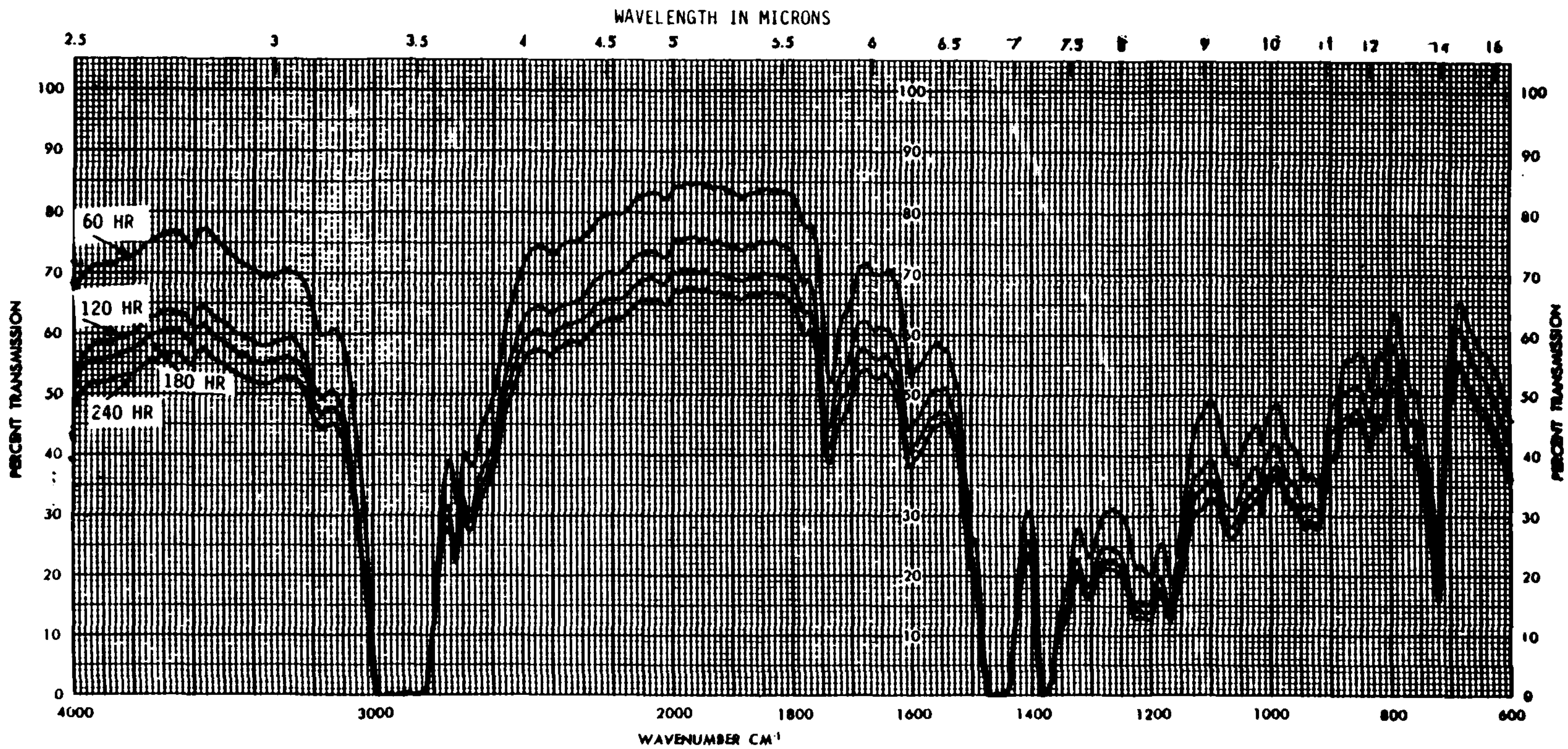
Lubricant: AL-12411-L Fuel: Caterpillar 1-H

	Maximum Power Mode (2800 RPM)		Maximum Torque Mode (2200 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	2800	0.368	2200	0.510
Torque, ft-lb (N-m)	554 (751)	3.7 (5.0)	614 (832)	4.2 (5.7)
Fuel Consumption, lb/hr (kg/hr)	119.4 (54.1)	0.85 (0.38)	102.0 (46.3)	0.66 (0.30)
Observed Power, Bhp (kW)	295.1 (220.0)	2.00 (1.49)	257.3 (191.9)	1.82 (1.36)
BSFC, lb/Bhp-hr (g/kW-hr)	0.404 (245.9)	0.004 (2.43)	0.396 (241.3)	0.004 (2.43)
Temperatures, °F (°C)				
Exhaust before Turbo	894.3 (479.0)	24.1 (13.4)	889.6 (476.4)	22.8 (12.7)
Exhaust after Turbo	769.4 (410.0)	27.5 (15.3)	772.2 (411.2)	12.0 (6.7)
Water Jacket Inlet	162.4 (72.4)	2.4 (1.3)	160.4 (71.3)	2.0 (1.1)
Water Jacket Outlet	172.2 (77.9)	1.8 (1.0)	170.0 (76.7)	0.9 (0.5)
Oil Sump	244.4 (118.0)	2.9 (1.6)	231.2 (110.7)	2.6 (1.4)
Fuel at Filter	98.1 (36.7)	2.4 (1.3)	96.7 (35.9)	2.4 (1.3)
Inlet Air	98.4 (36.9)	3.7 (2.1)	97.0 (36.1)	3.7 (2.1)
Airbox	280.3 (137.9)	4.8 (2.7)	234.6 (112.6)	3.6 (2.0)
Pressures				
Exhaust before Turbo, psi (kPa)	12.4 (85.5)	0.63 (4.3)	8.63 (59.5)	0.39 (2.69)
Exhaust after Turbo, in. Hg (kPa)	2.1 (7.1)	0.30 (1.0)	1.3 (4.4)	0.20 (0.68)
Compressor Discharge, psi (kPa)	13.0 (89.6)	0.89 (6.1)	9.8 (67.6)	0.66 (4.55)
Blower Discharge, psi (kPa)	18.4 (126.9)	1.74 (12.0)	11.4 (78.6)	0.51 (3.5)
Oil Gallery, psi (kPa)	42.5 (293.0)	0.56 (3.9)	39.8 (274.4)	1.90 (13.1)
Intake Vacuum, in. H_2O (kPa)	5.0 (1.2)	1.47 (0.36)	3.4 (0.85)	0.68 (0.17)
Ambient Conditions				
Dry Bulb Temperature, °F (°C)	82.3 (27.9)	6.25 (3.5)	80.8 (27.1)	6.09 (3.38)
Wet Bulb Temperature, °F (°C)	70.6 (21.4)	4.20 (2.3)	69.8 (21.0)	4.46 (2.48)
Barometric Pressure, in. Hg (kPa)	29.16 (98.5)	0.11 (0.37)		

*68% of the values for a given variable occur within ±1 standard deviation of the mean; 95% occur within ±2 standard deviations.

6V-53T
TEST 37
INFRARED SPECTRUM

Lubricant: AL-12411-L



6V-53T
TEST 37
LUBRICANT ANALYSIS

Lubricant: AL-12411-L

	ASTM Test Method	Test Time, Hours												
		0	20	40	60	80	100	120	140	160	180	200	220	240
Kinematic Viscosity at 40°C (104°F) cSt	D 445	102.96	--	--	102.56	--	--	106.29	--	--	106.1	--	--	108.41
Kinematic viscosity at 100°C (212°F) cSt	D 445	11.54	11.67	11.84	11.80	11.95	11.76	12.03	11.65	11.67	11.80	11.83	12.25	12.26
Total Acid Number mg KOH/g	D 664	2.88	--	--	2.98	--	--	2.93	--	--	3.08	--	--	3.14
Total Base Number mg KOH/g	D 664	4.62	--	--	3.91	--	--	3.30	--	--	3.61	--	--	2.87
Pentane B Insolubles wt%	D 893	0.01	--	--	0.07	--	--	0.19	--	--	0.16	--	--	0.23
Toluene B Insolubles wt%	D 893	0.01	--	--	0.04	--	--	0.17	--	--	0.13	--	--	0.19
Flash Point, °C	D 92	232	--	--	--	--	--	235	--	--	--	--	--	243

6V-53T
TEST 37
TOTAL CONSUMPTION AND WEAR METALS BY XRF

Lubricant: AL-12411-L

Test Time, Hours	Total Oil Consumed, lb (kg)		Wear Metals, ppm Fe	Cu
0	--		--	--
20	7.06	(3.20)	45	13
40	13.87	(6.29)	126	15
60	20.83	(9.45)	53	14
80	35.07	(15.91)	59	<10
100	42.04	(19.07)	62	<10
118	48.88	(22.17)		
120	Oil Change		55	<10
140	49.24	(22.33)	30	<10
160	56.14	(25.46)	41	<10
180	63.17	(28.65)	56	<10
200	77.49	(35.15)	47	<10
220	89.57	(40.63)	59	<10
240	107.64	(48.82)	56	<10

Average oil consumption rate: 0.45 lb/hr (0.20 kg/hr)

6V-53T
TEST 37
WEAR MEASUREMENTS*

Lubricant: AL-12411-L

Cylinder Liner Bore Diameter Change

Cylinder Number

	1L T-AT**	1L F-B	2L T-AT	2L F-B	3L T-AT	3L F-B
Top	0.0012 (0.030)	0.0013 (0.008)	0.0019 (0.048)	0.0006 (0.015)	0.0013 (0.033)	-0.0007 (-0.018)
Middle	0.0006 (0.015)	0.0004 (0.010)	0.0005 (0.013)	0.0007 (0.018)	0.0007 (0.018)	0.0002 (0.005)
Bottom	0.0004 (0.010)	0.0011 (0.028)	0.0010 (0.025)	0.0006 (0.015)	0.0002 (0.005)	0.0006 (0.015)

Cylinder Number

	1R T-AT	1R F-B	2R T-AT	2R F-B	3R T-AT	3R F-B
Top	0.0028 (0.071)	0.0007 (0.018)	0.0008 (0.020)	0.0005 (0.013)	0.0014 (0.036)	0.0002 (0.005)
Middle	0.0006 (0.015)	0.0009 (0.022)	0.0005 (0.013)	0.0006 (0.015)	0.0011 (0.028)	0.0006 (0.015)
Bottom	0.0003 (0.008)	0.0006 (0.015)	0.0005 (0.013)	0.0000	0.0004 (0.010)	0.0004 (0.010)

Average Change

	T-AT	F-B
Top	0.0016 (0.041)	0.0003 (0.008)
Middle	0.0007 (0.018)	0.0006 (0.015)
Bottom	0.0005 (0.013)	0.0006 (0.015)

Overall average change: 0.0007 (0.018)

Piston Ring End Gap Change

Ring Number	1L	2L	3L	1R	2R, 40 hrs***	2R, 240 hrs	3R	Average Change
1	0.006 (0.15)	0.003 (0.07)	0.005 (0.13)	0.006 (0.15)	0.004 (0.10)	0.001 (0.02)	0.005 (0.13)	0.004 (0.10)
2	0.005 (0.13)	0.003 (0.07)	0.003 (0.07)	0.004 (0.10)	0.000	0.002 (0.05)	0.002 (0.05)	0.003 (0.07)
3	0.002 (0.05)	0.002 (0.05)	0.004 (0.10)	0.002 (0.05)	0.001 (0.02)	0.001 (0.02)	0.002 (0.05)	0.002 (0.05)
4	0.003 (0.07)	0.001 (0.02)	0.007 (0.18)	0.005 (0.13)	0.002 (0.05)	0.001 (0.02)	0.002 (0.05)	0.003 (0.07)
5	0.005 (0.13)	0.006 (0.15)	0.006 (0.15)	0.006 (0.15)	0.008 (0.20)	0.007 (0.18)	0.004 (0.10)	0.006 (0.15)
6	0.006 (0.15)	0.005 (0.13)	0.008 (0.20)	0.006 (0.15)	0.003 (0.07)	0.006 (0.15)	0.002 (0.05)	0.006 (0.15)
7	0.006 (0.15)	0.006 (0.15)	0.005 (0.13)	0.005 (0.13)	0.002 (0.05)	0.004 (0.10)	0.006 (0.15)	0.005 (0.13)

Overall average change: 0.004 (0.10)

* All dimensions are given in inches (mm).
** T-AT = Thrust-Antithrust Direction; F-B = Front-Back Direction.
*** These measurements are omitted from the averages.

6V-53T
TEST 37
POST TEST ENGINE CONDITION AND DEPOSITS

Lubricant: AL-12411-L

	Cylinder Number							
	1L	2L	3L	1R	2R* (0-40 hrs)	2R (40-240 hrs)	3R	Average
A. Cylinder Liner								
Intake Port Plugging, % restriction	<1	<1	<1	<1	<1	<1	<1	<1
Liner Scuffing, % Area								
Thrust	24	32	10	72	47	36	28	33.67
Anti-Thrust	0	5	10	8	100	1	1	4.17
% Total Area Scuffing	12	18.5	10	40	73.5	18.5	14.5	18.92
							Overall:	18.92
% Area Bore Polished								
Thrust	8	2	10	9	1	4	1	5.67
Anti-Thrust	6	10	7	10	0	9	10	8.67
% Avg. Area Bore Polished	7	6	8.5	9.5		6.5	5.5	7.17
							Overall:	7.17
B. Pistons								
Ring Face Distress, (demerits)								
No. 1	5.50	9.00	2.50	3.5	51.75	5.5	5.5	5.25
No. 2	.75	1.25	20.00	22.5	25	12.5	15.25	12.04
No. 3	.50	8.75	26.25	27.5	25	23.75	18.75	17.58
No. 4	0	6.25	20	26.25	25	23.75	11.25	87.50
							Overall:	30.59
Piston Skirt Rating								
Thrust	S**	5%SC	S	20%SC	15%PM, 60%SC	5%SC	10%SC	—
Anti-Thrust	20%SC	10%SC	S	S	S	S	S	--
Upper Oil Control Ring Expander Force (lbs)	19	19.4	19.8	19.2	23	20	19.4	19.5
Piston WTD Rating***	234.500	259.750	227.500	229.000	148.75	231.000	240.000	236.96
Ring Sticking								
No. 1	F+	F	F	F		F	F	
No. 2	S	F	F	F		F	F	
No. 3	F	F	F	F		F	F	
No. 4	F	F	F	F		F	F	
C. Exhaust Valves								
Deposits+								
Head	AHC, 1/4AHC++	1/2AHC, 1/4AHC	AHC, 1/4AHC	AHC, 1/4AHC		AHC	AHC, 1/4AHC	
Face	----1/4AHC----							
Tulip	----AHC----							
Stem	----1/4AHC, #9 Lacquer+++----							
Surface Condition								
Freeness in Guide	F	F	F	F		F	F	
Head	----Normal----							
Face	----Normal----							
Seat	----Normal----							
Stem	----Normal----							
Tip	----Normal----							

D. Other Ratings

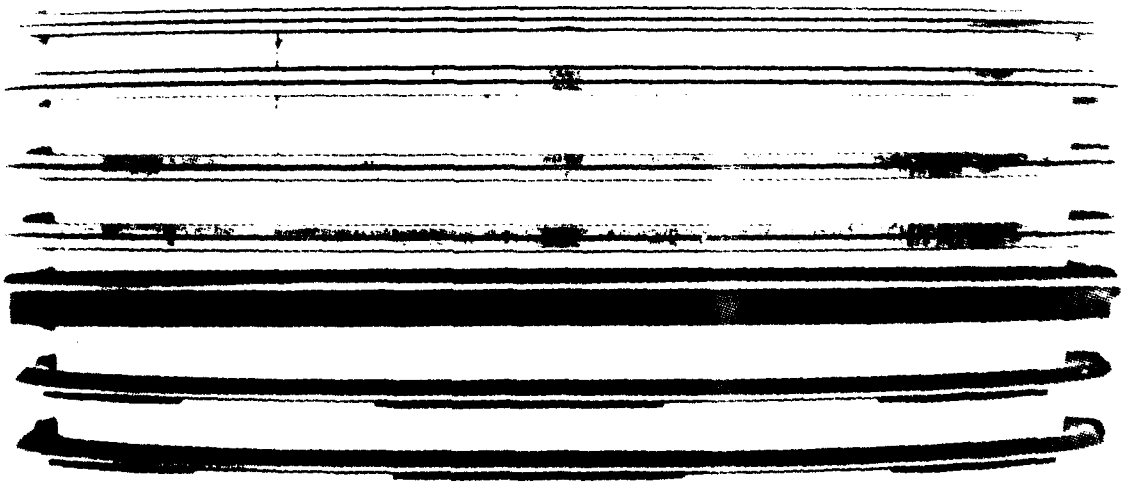
Bearing Surface Condition

Main Bearings	Number 1, 2 and 3 main bearings have deep scratches (to copper).
Rod Bearings	No abnormalities.

* These measurements are omitted from all averages
** L = Light, S = Scratches, PM = Plating Melted, N = Normal, SC = Scuffing, B = Burn
*** CRC Weighted Total Deposits (0 = least, 900 = most)
\+ HS = Hot Stuck, CS = Cold Stuck, P = Pinched, F = Free, N = Normal, C = Chipped, S = Sluggish
++ HC = Hard Carbon; the number-letter, prefix indicates carbon depth with 1/4A = least to J = most
+++ The higher the number, the darker the lacquer (0 = lightest, 9 = darkest)

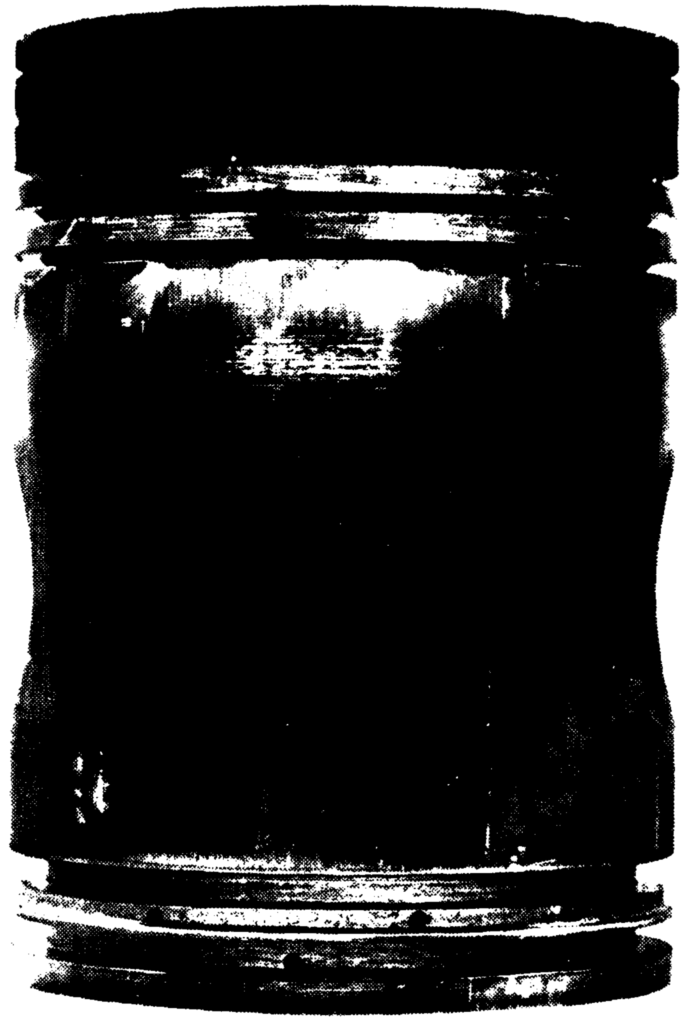
6V53T(#37)
1-L

6V53T(#37)
1-R



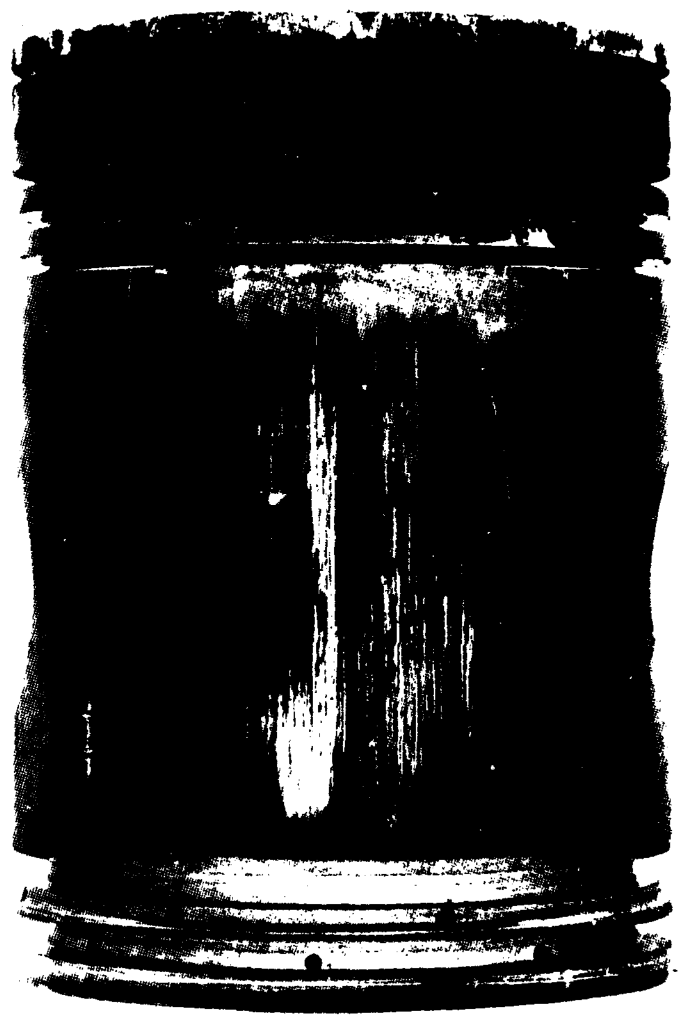
6V53T(#37)
1-R-T

6V53T(#37)
1-R-AT

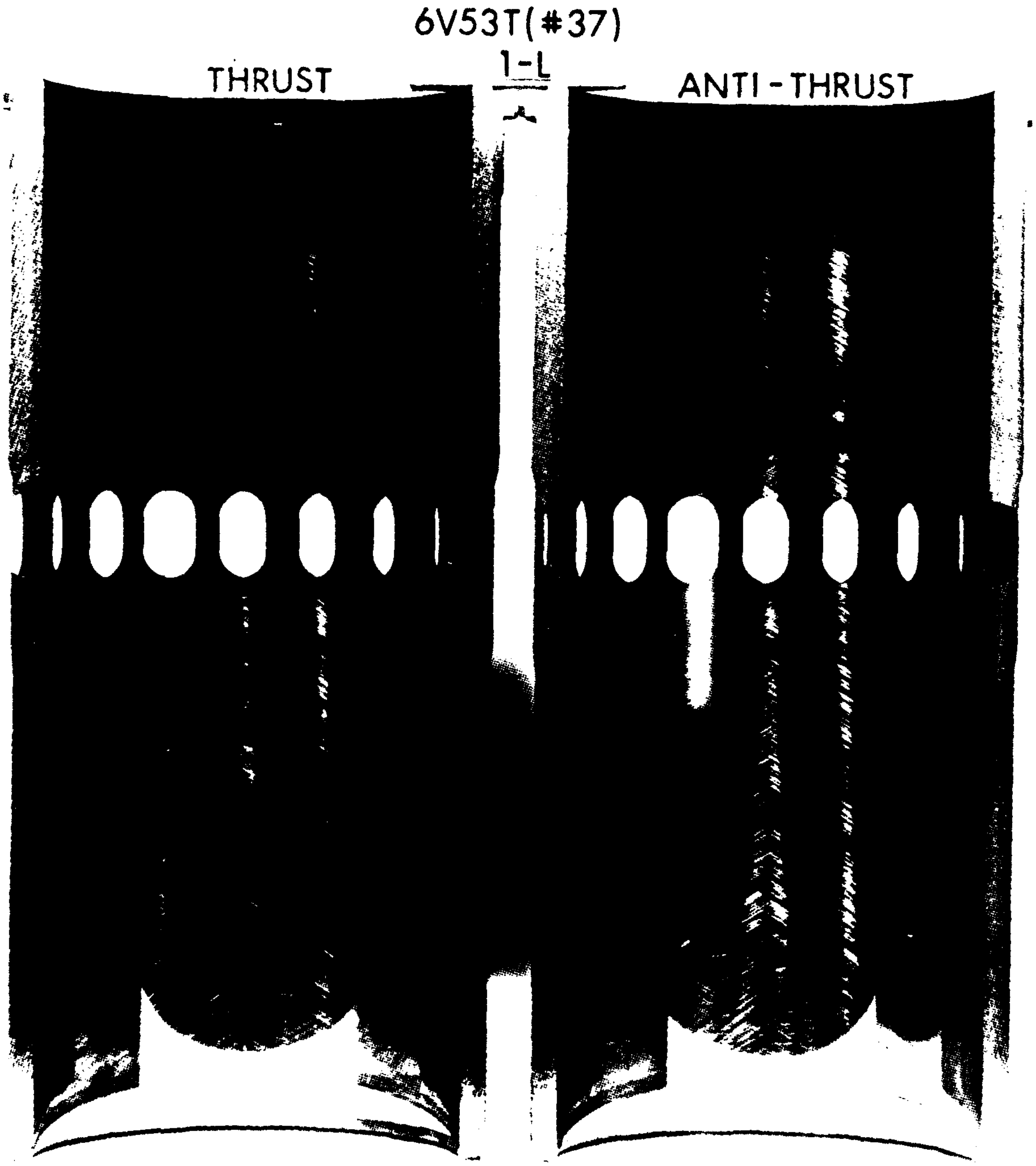


6V53T (#37)
1-L-T

6V53T (#37)
1-L-AT



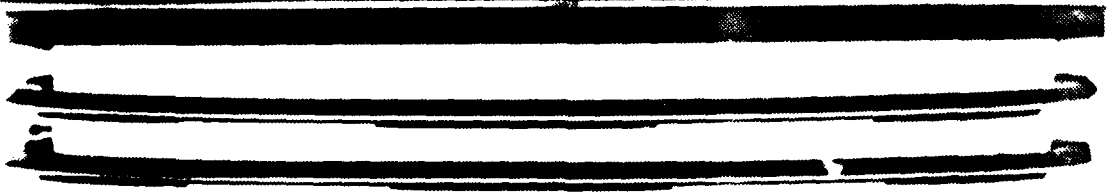

6V53T(#37)
1-R
THRUST
ANTI-THRUST



6V53T(#37)
THRUST
1-L
ANTI-THRUST

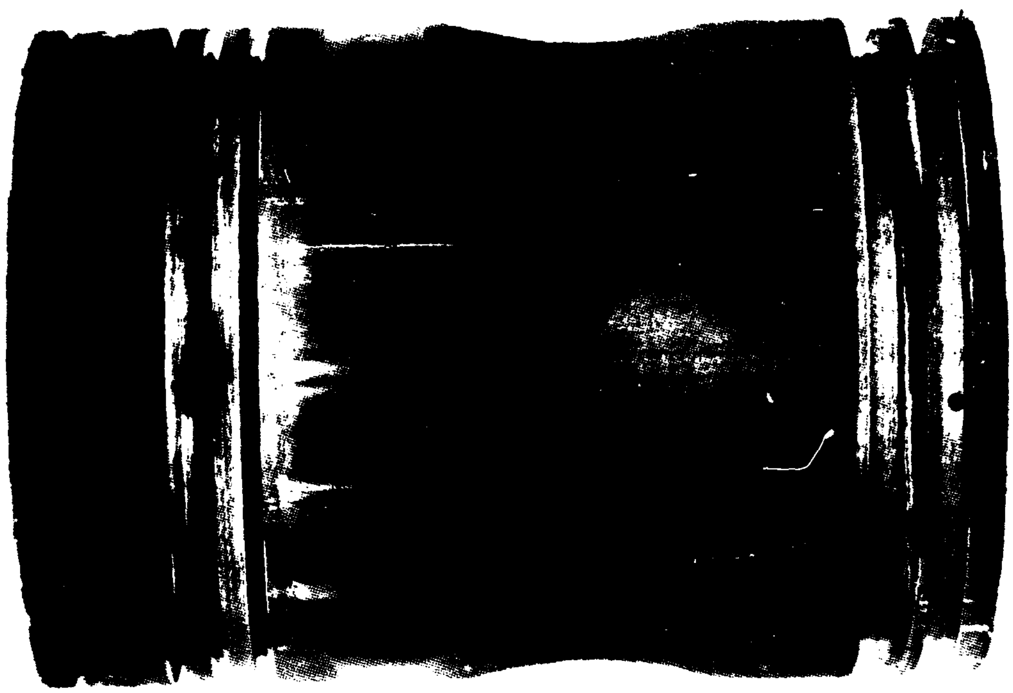
6V53T(#37)
2-L

6V53T(#37)
2-R



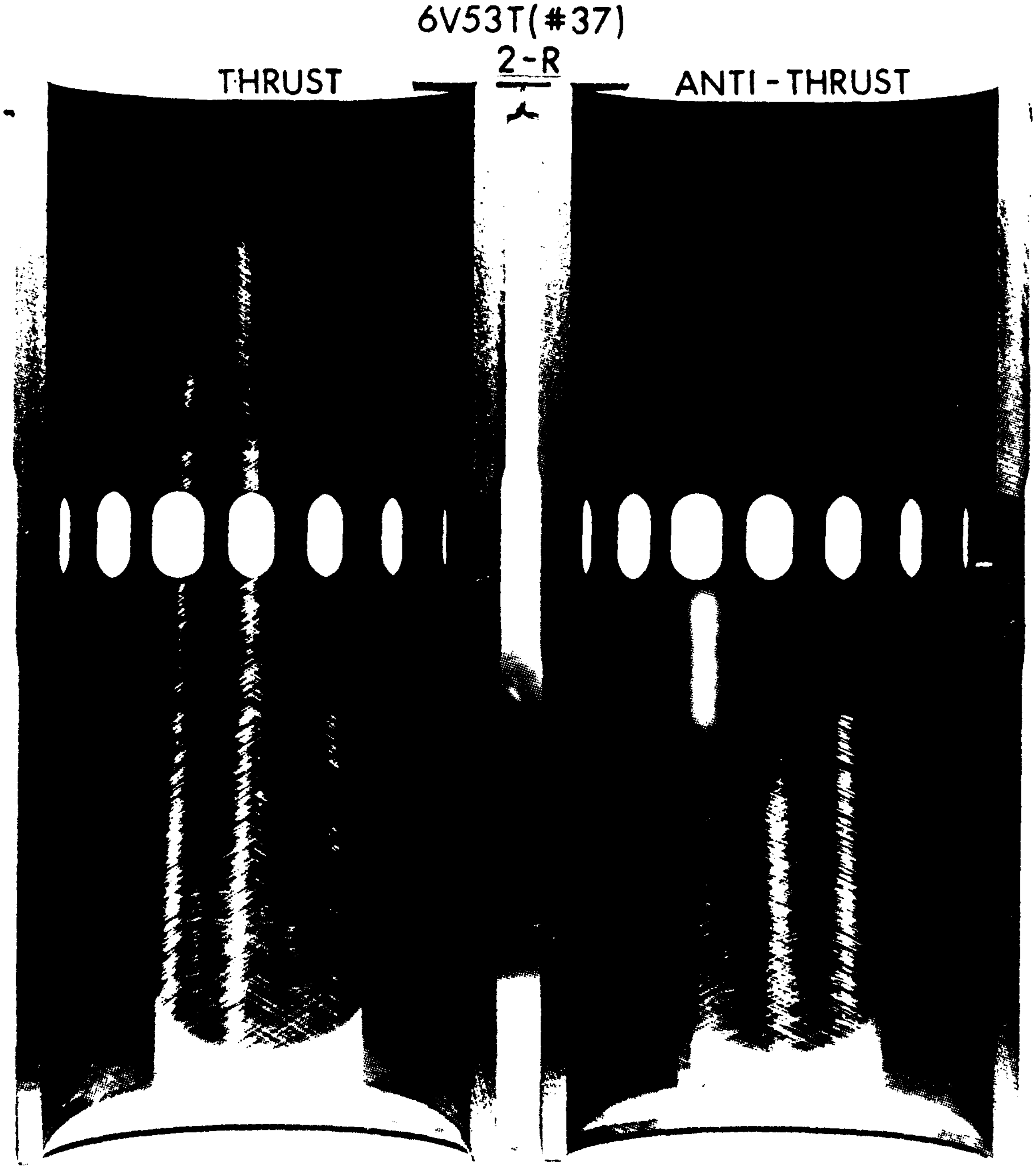
6V53T(#37)
2-R-T

6V53T(#37)
2-R-AT



6V53T(#37)
2-L-T

6V53T(#37)
2-L-AT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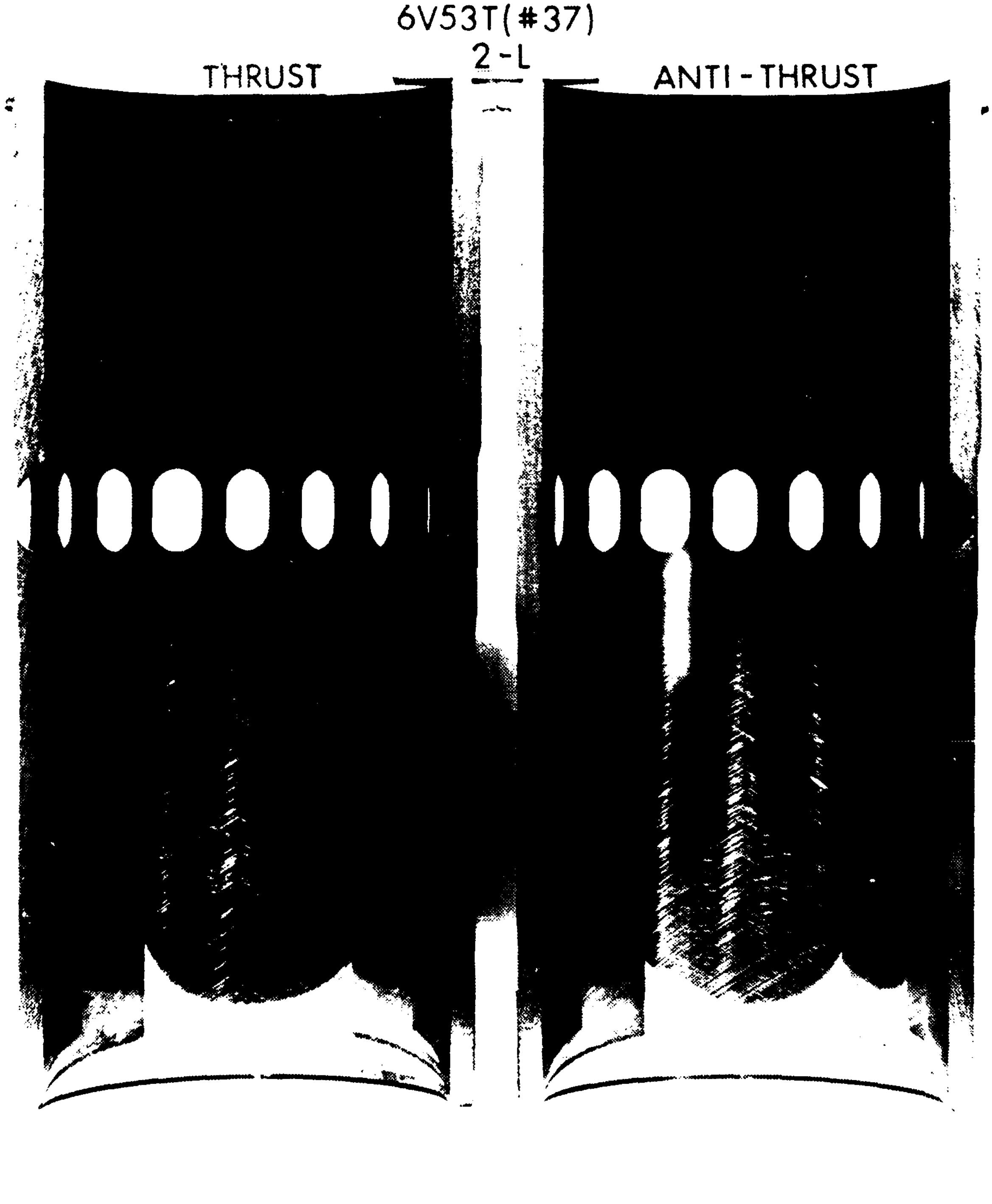
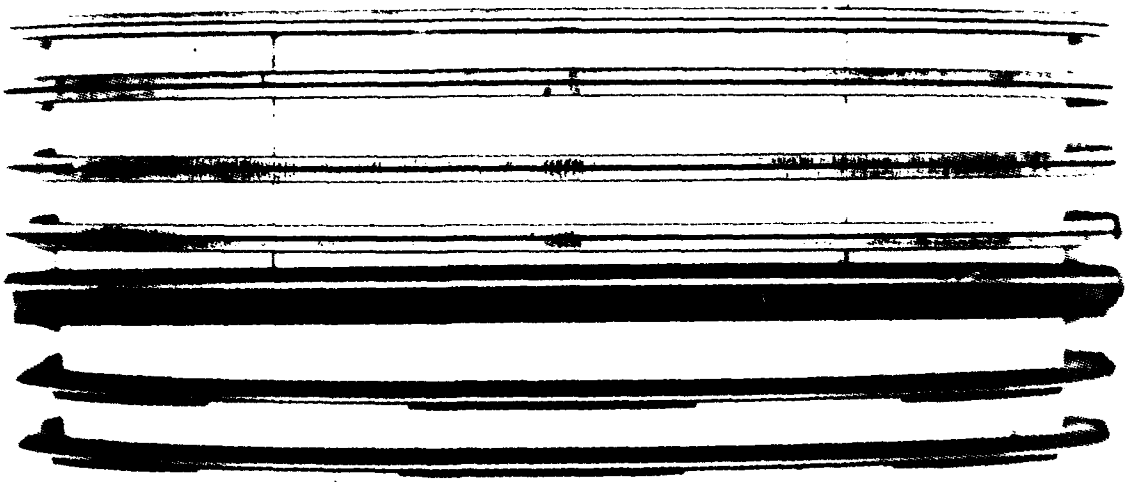
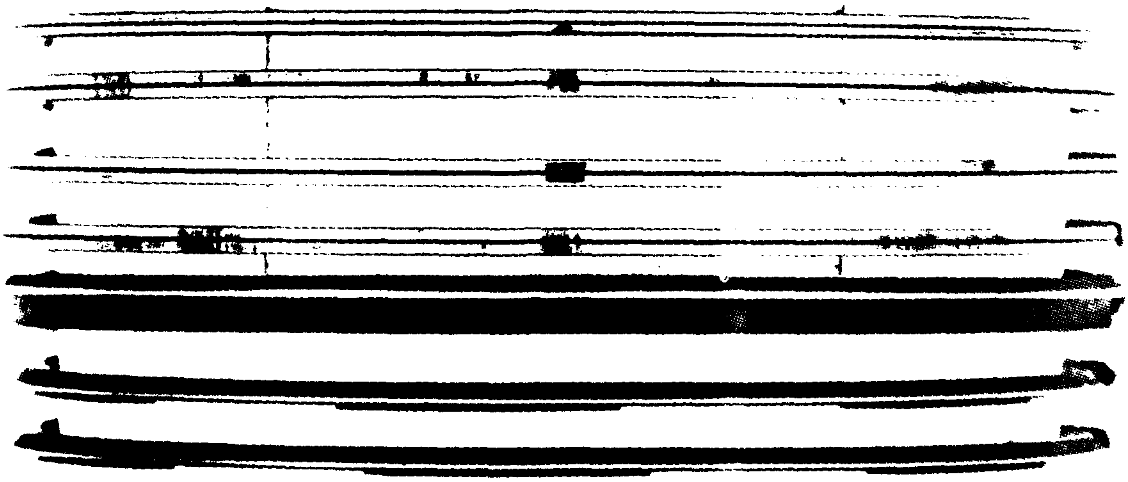
2-R
THRUST
ANTI-THRUST


6V53T(#37)
2-L
THRUST
ANTI-THRUST

6V53T(#37)
3-L



6V53T(#37)
3-R

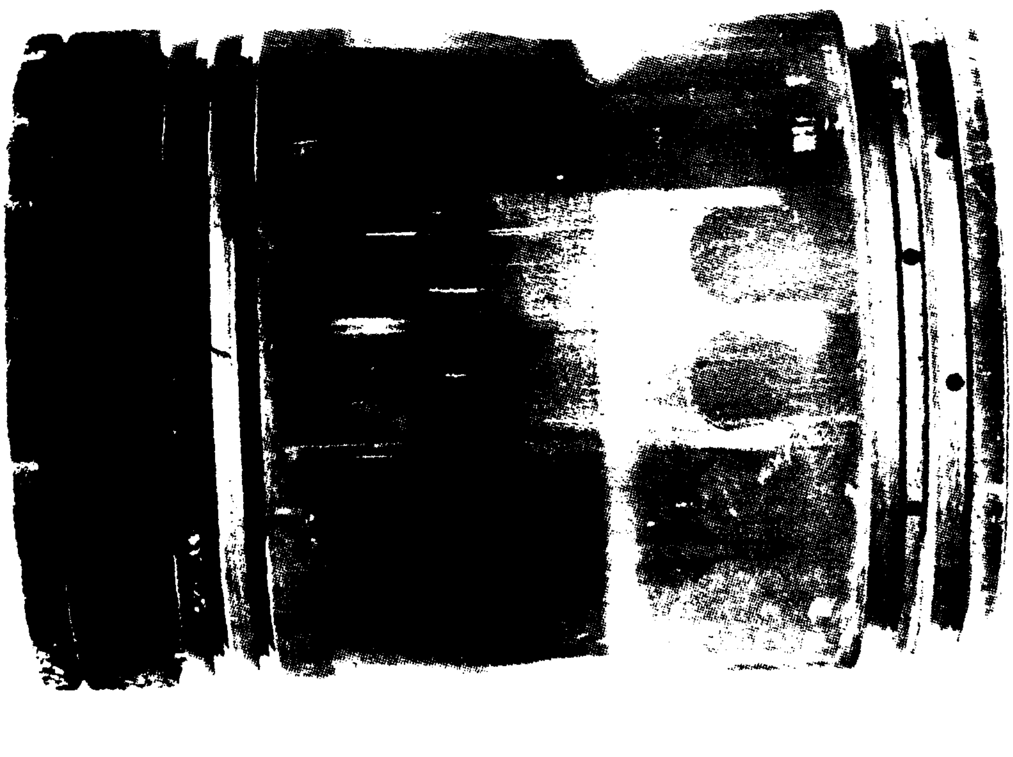


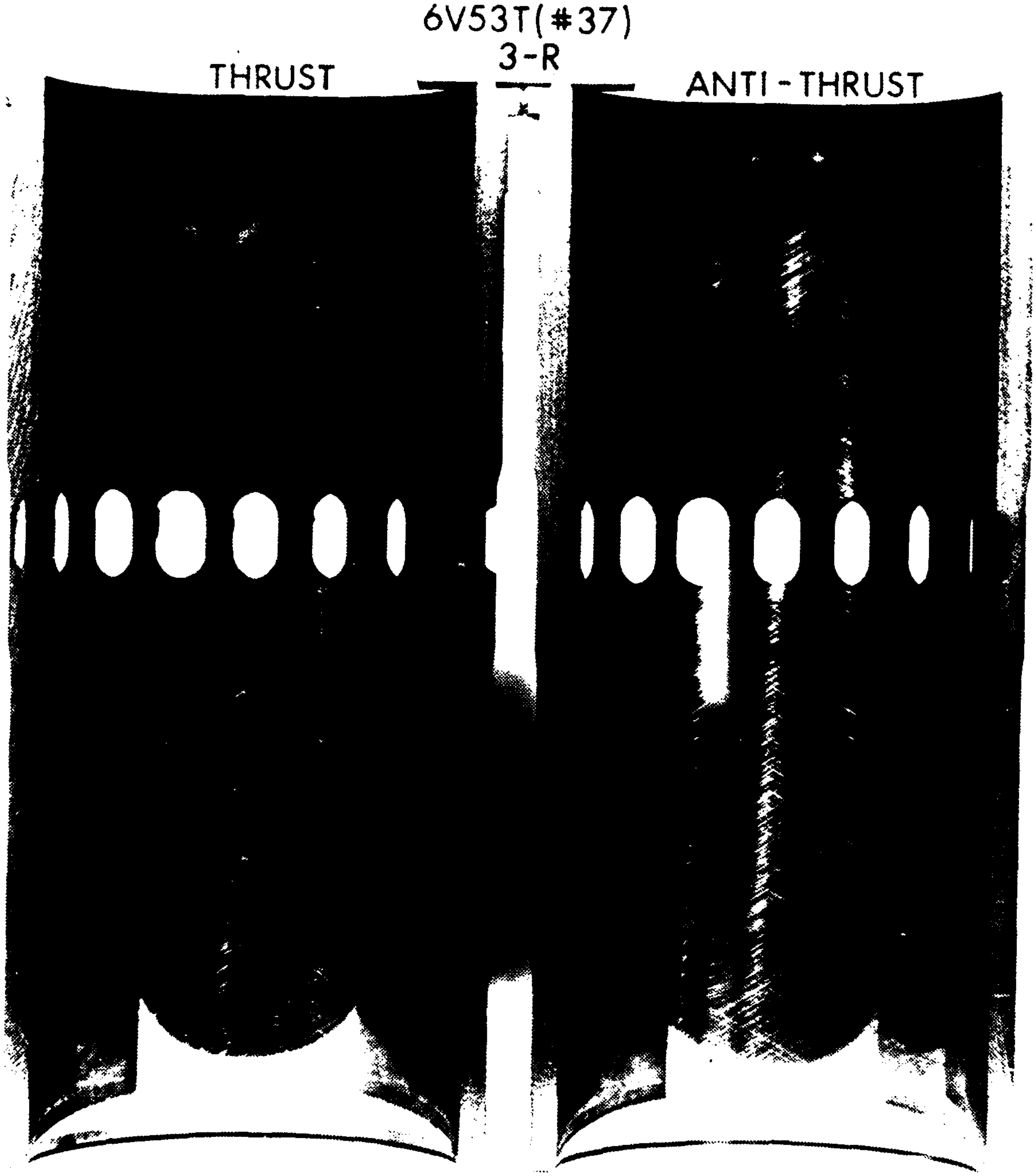
6V53T(#37)
3-R-T

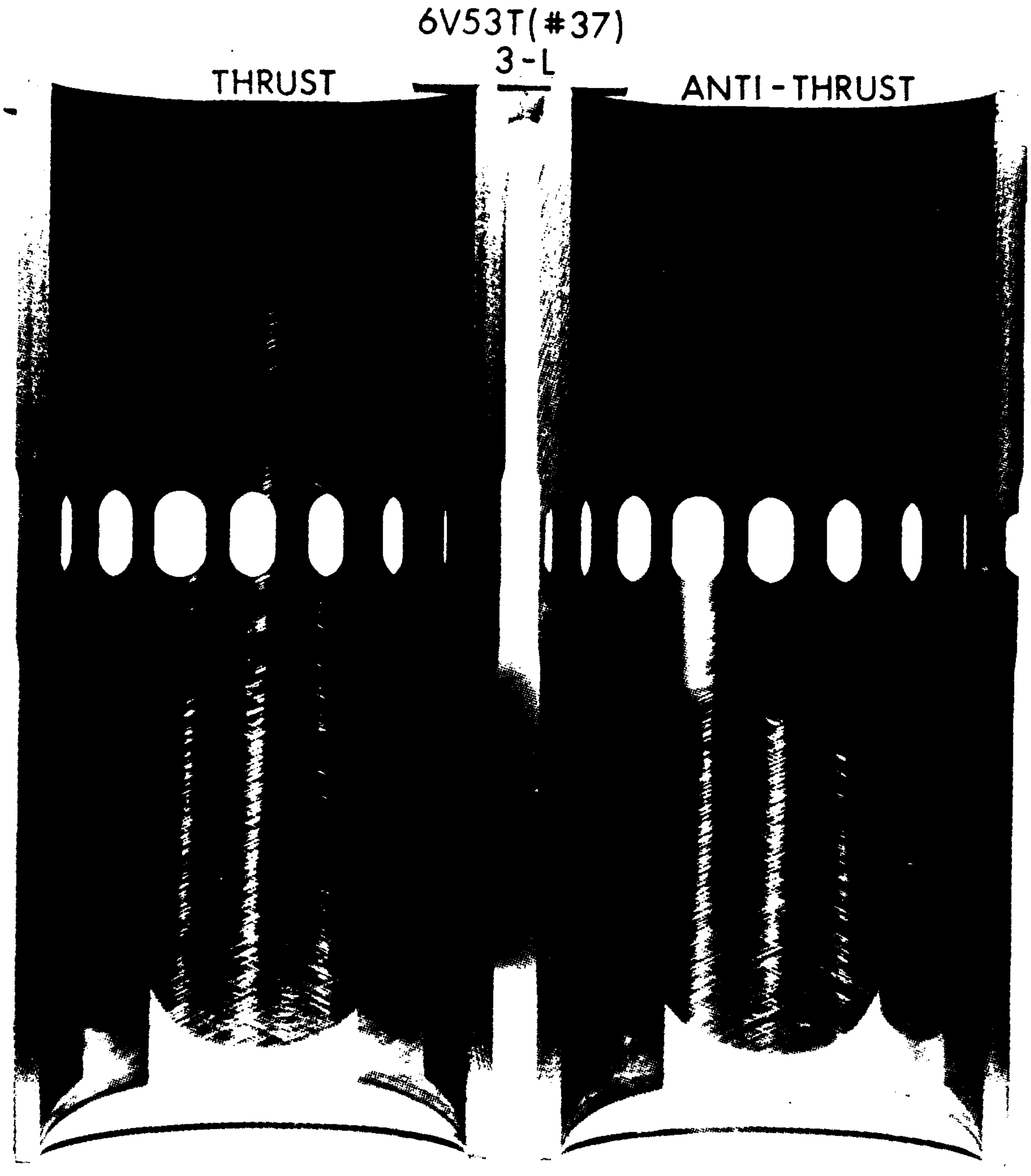
6V53T(#37)
3-R-AT

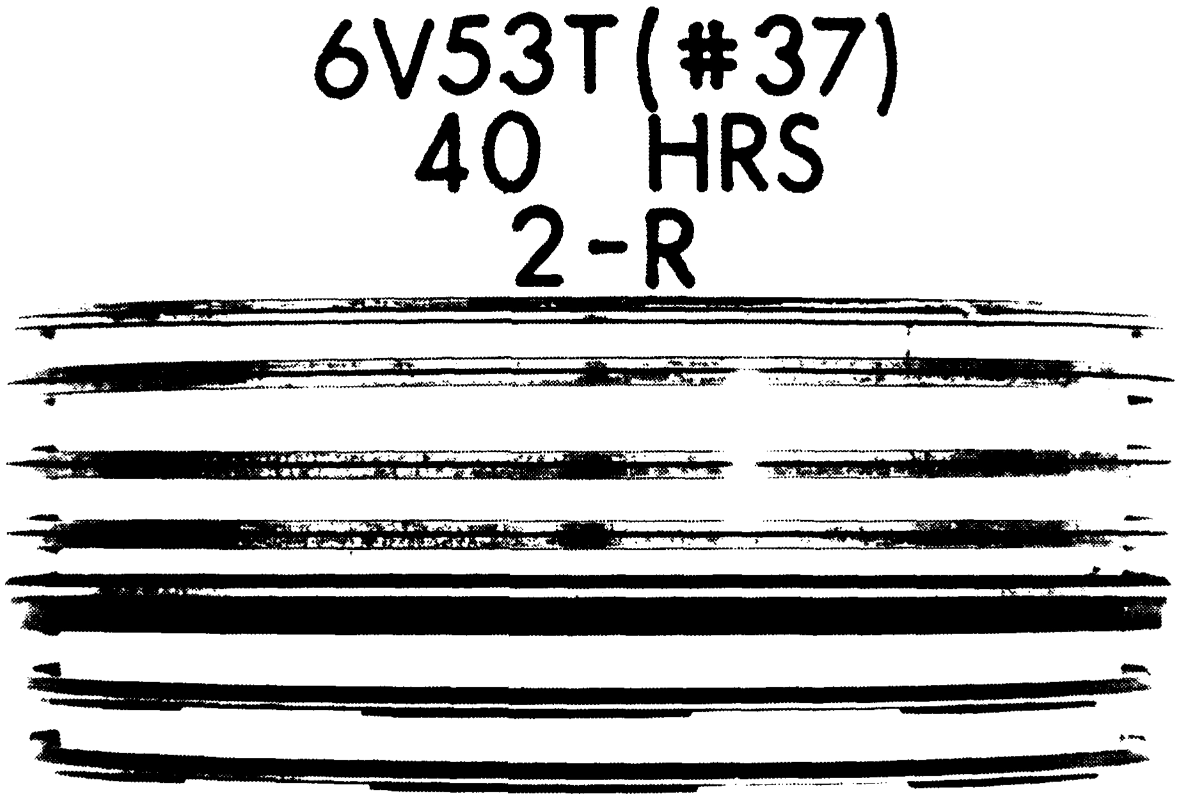
6V53T(#37)
3-L-AT

6V53T(#37)
3-L-T



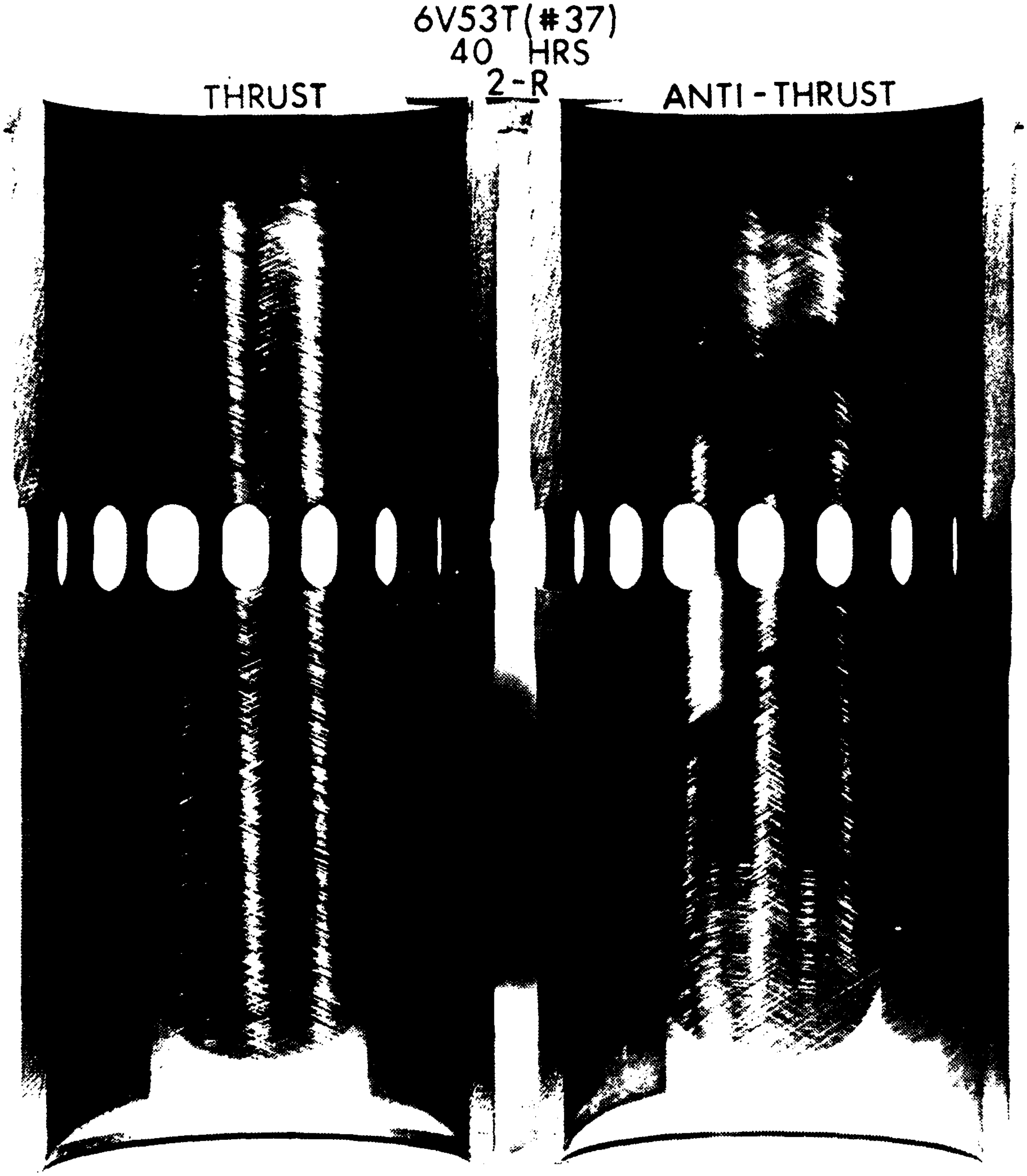

6V53T(#37)
3-R
THRUST
ANTI-THRUST

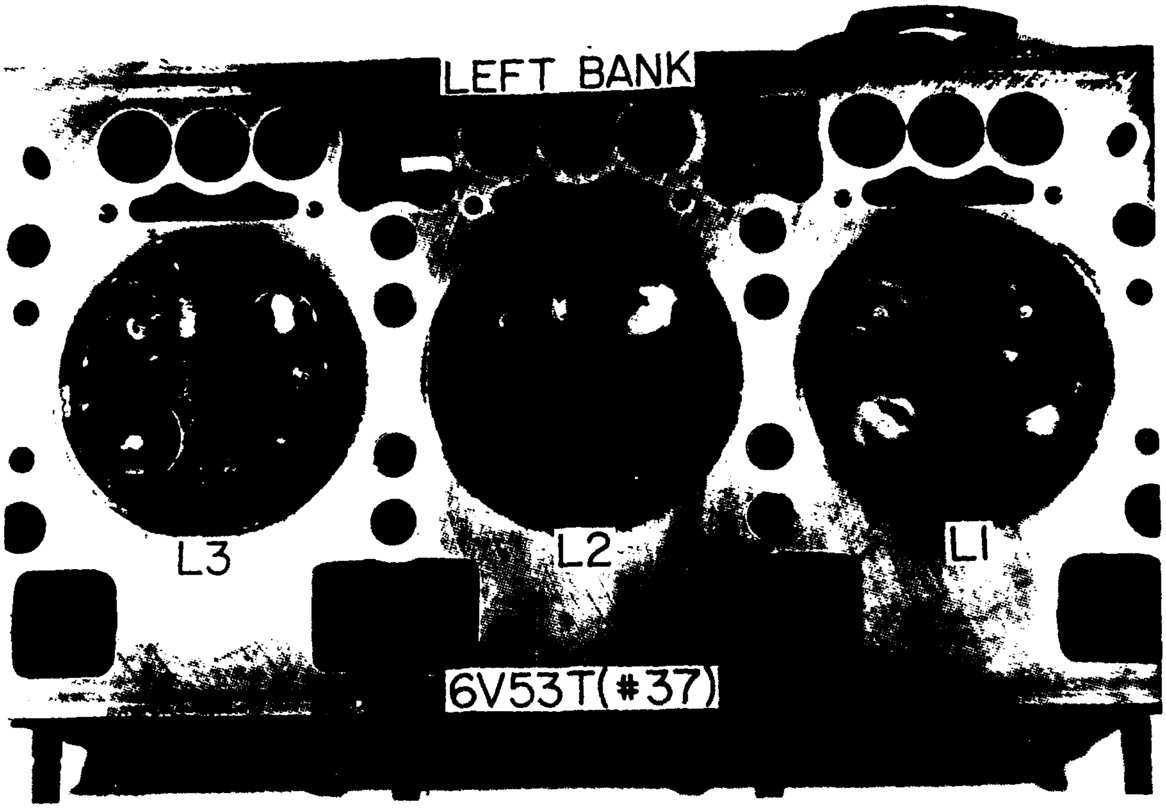

6V53T(#37)
3-L
THRUST
ANTI-THRUST

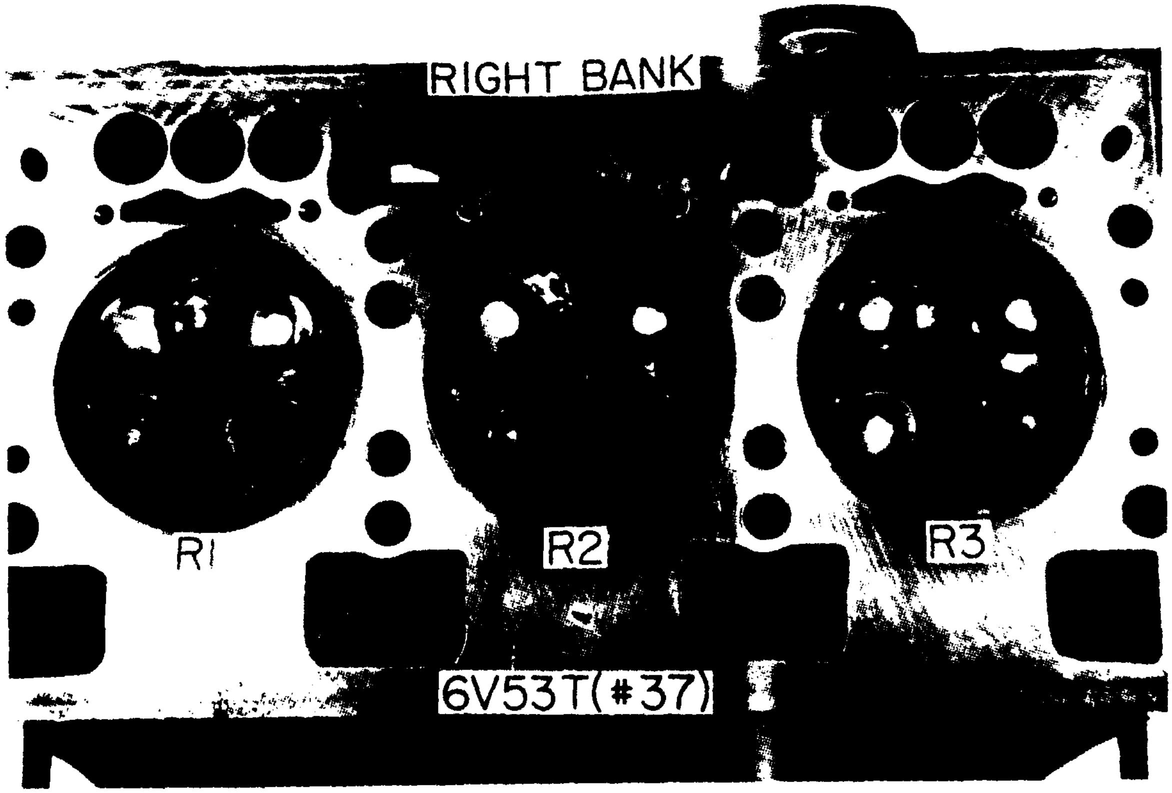

6V53T(#37)
40 HRS
2-R

6V53T(#37)
40 HRS
2-R-AT

6V53T(#37)
40 HRS
2-R-T


6V53T(#37)
40 HRS
2-R
THRUST
ANTI-THRUST


LEFT BANK
L3
L2
L1
6V53T(#37)


RIGHT BANK
R1
R2
R3
6V53T(#37)

APPENDIX J

Test Data and Photographs

DD 6V-53T Engine

240-Hour Test

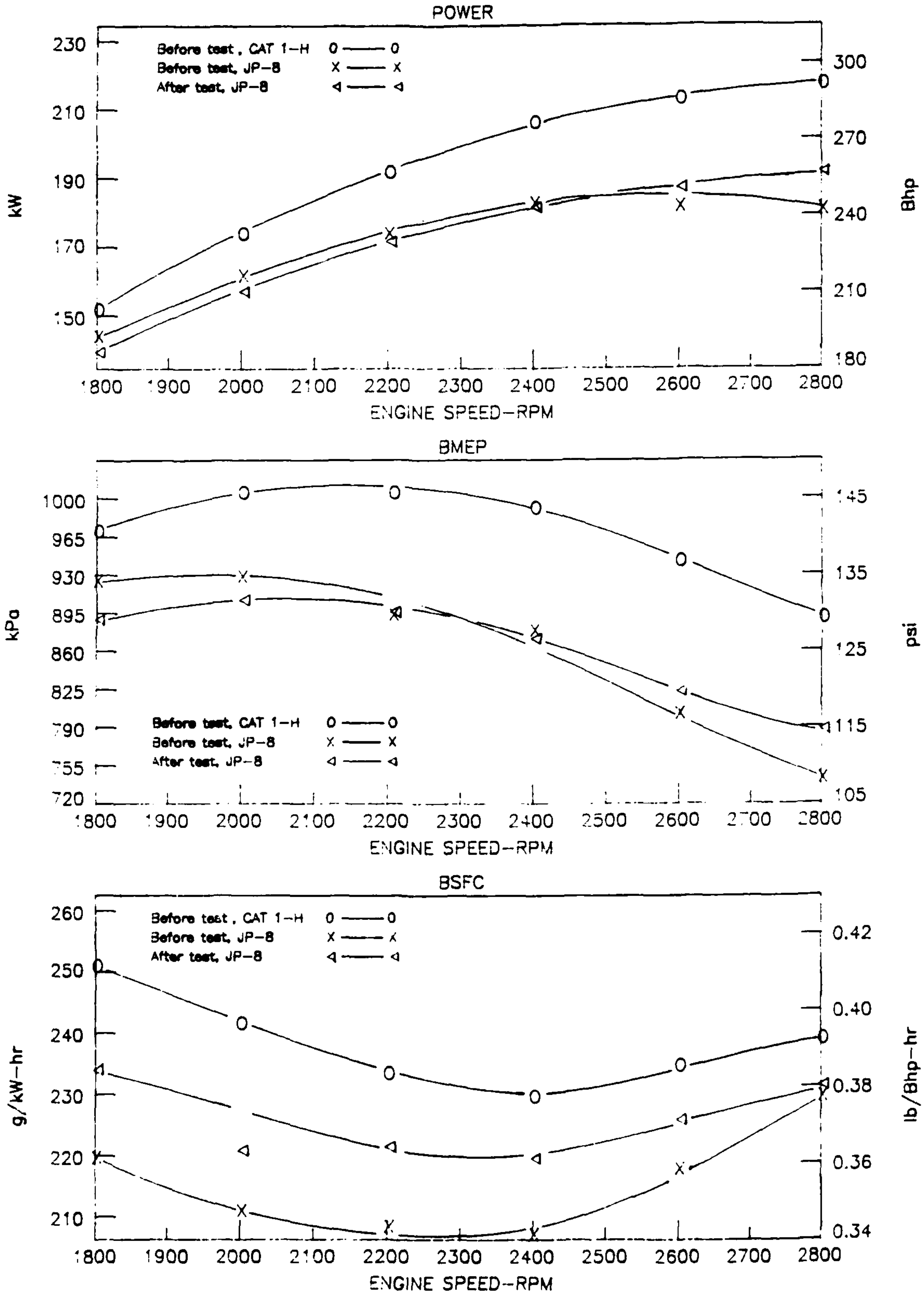
JP-8 Fuel

6V-53T
TEST 39
ENGINE REBUILD MEASUREMENTS*
Model Number: 5063-5395
Serial Number: 6D-157211

	Min	Max	Avg	Specified Limits	
Cylinder Block Bore					
Inside Diameter (Bottom)	4.3567 (110.660)	4.3578 (110.688)	4.357 ~~0.3572~~ (110.675)	4.3565 (110.655)	- 4.3575 (110.681) New - 4.3595 (110.731) Max
Out-of-Round	0.0001 (0.0025)	0.0008 (0.020)	0.0005 (0.013)		- 0.0015 (0.038) Max
Taper	0.0000	0.0004 (0.010)	0.0001 (0.003)		- 0.0015 (0.038) Max
Cylinder Liners (Installed)					
Inside Diameter	3.8754 (98.435)	3.8766 (98.466)	3.8760 (98.450)	3.8752 (98.430)	- 3.8767 (98.468)
Out-of-Round	0.0000	0.0007 (0.018)	0.0003 (0.008)		- 0.0015 (0.038) Max
Taper	0.0000	0.0006 (0.015)	0.0003 (0.008)		- 0.0015 (0.038) Max
Piston Diameter (at skirt)	3.8677 (98.240)	3.8686 (98.262)	3.8681 (98.250)	3.8669 (98.219)	- 3.8691 (98.775)
Piston Skirt to Cylinder Liner Clearance	0.0070 (0.178)	0.0086 (0.218)	0.0082 (0.208)	0.0061 (0.155)	- 0.0098 (0.249)
Compression Rings					
Gap (No. 1, Fire Ring)	0.031 (0.79)	0.035 (0.89)	0.034 (0.86)	0.020 (0.51)	- 0.046 (1.17)
Gap (Nos. 2, 3, 4)	0.025 (0.64)	0.033 (0.84)	0.029 (0.74)	0.020 (0.51)	- 0.036 (0.91)
Ring-to-Groove Clearance					
Top (No. 1, Fire Ring)	0.003 (0.08)	0.004 (0.10)	0.004 (0.10)	0.003 (0.08)	- 0.006 (0.15)
No. 2, Compression Ring	0.008 (0.20)	0.008 (0.20)	0.008 (0.20)	0.007 (0.18)	- 0.010 (0.25)
No. 3 and 4, Compression Rings	0.005 (0.13)	0.006 (0.15)	0.006 (0.15)	0.005 (0.13)	- 0.008 (0.20)
Oil Control Rings, Nos. 5, 6, 7					
Gap	0.013 (0.33)	0.016 (0.41)	0.014 (0.36)	0.010 (0.25)	- 0.025 (0.64)
Ring-to-Groove Clearance	0.002 (0.05)	0.004 (0.10)	0.003 (0.08)	0.0015 (0.038)	- 0.0055 (0.140)
Piston Pin					
Pin-to-Piston Bushing Clearance	0.0028 (0.071)	0.0030 (0.076)	0.0029 (0.074)	0.0025 (0.064)	- 0.0034 (0.086)
Pin-to-Connecting Rod Bushing Clearance	0.0013 (0.033)	0.0017 (0.043)	0.0014 (0.036)	0.0010 (0.025)	- 0.0019 (0.048)
Connecting Rod Bearing-to-Journal Clearance	0.0021 (0.053)	0.0032 (0.081)	0.0026 (0.066)	0.0011 (0.028)	- 0.0041 (0.104)
Main Bearing-to-Journal Clearance	0.0041 (0.104)	0.0044 (0.111)	0.0042 (0.107)	0.0010 (0.025)	- 0.0040 (0.102)
Camshaft Bearing-to-Journal Clearance	0.0050 (0.127)	0.0056 (0.142)	0.0053 (0.135)	0.0045 (0.114)	- 0.0060 (0.152)

* Measurements are in inches and (mm). All rebuild measurements omit the data for the 2A piston-liner-ring kit removed at 25 hours, and use instead the 2R kit which completed the test.

6V-53T 240-HOUR TRACKED VEHICLE CYCLE
BEFORE AND AFTER TEST 39 PERFORMANCE DATA



6V-53T
240-HOUR TRACKED VEHICLE CYCLE ENDURANCE TEST
TEST 39
OPERATING CONDITIONS SUMMARY

Lubricant: AL-12634-L Fuel: AL-12780-F (JP-8)

	Maximum Power Mode (2800 RPM)		Maximum Torque Mode (2200 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	2800	5.38	2200	3.56
Torque, ft-lb (N-m)	481 (652)	4.50 (6.10)	559 (758)	5.92 (8.03)
Fuel Consumption, lb/hr (kg/hr)	97.7 (44.3)	0.65 (0.296)	83.9 (38.1)	0.415 (0.189)
Observed Power, Bhp (kW)	256 (191)	2.34 (1.75)	234 (175)	2.40 (1.79)
BSFC, lb/Bhp-hr (g/kW-hr)	0.381 (232)	0.003 (1.70)	0.359 (218)	0.004 (2.52)
Temperatures, °F (°C)				
Exhaust before Turbo	901 (483)	28.4 (15.8)	900 (482)	25.7 (14.3)
Exhaust after Turbo	747 (397)	18.4 (10.2)	793 (423)	23.8 (13.2)
Water Jacket Inlet	159 (70.4)	1.45 (0.806)	159 (70.3)	1.49 (0.826)
Water Jacket Outlet	170 (76.4)	1.62 (0.900)	170 (76.5)	1.56 (0.869)
Oil Sump	234 (112)	2.87 (1.60)	226 (108)	2.67 (1.49)
Fuel at Filter	97 (35.8)	9.23 (5.13)	93 (33.9)	2.25 (1.25)
Inlet Air	92 (32.9)	3.21 (1.78)	93 (33.9)	4.29 (2.38)
Airbox	263 (129)	2.76 (1.53)	221 (105)	2.59 (1.44)
Pressures				
Exhaust before Turbo, psi (kPa)	9.32 (64.3)	0.318 (2.20)	5.35 (36.9)	0.176 (1.22)
Exhaust after Turbo, in. Hg (kPa)	2.09 (7.06)	0.093 (0.31)	1.15 (3.88)	0.070 (0.24)
Compressor Discharge, psi (kPa)	9.76 (67.3)	0.435 (3.00)	6.73 (46.4)	0.873 (6.02)
Blower Discharge, psi (kPa)	16.4 (113)	0.515 (3.55)	9.05 (62.4)	0.367 (2.53)
Oil Gallery, psi (kPa)	57.1 (394)	0.636 (4.38)	52.6 (363)	0.724 (5.00)
Intake Vacuum, in. H_2O (kPa)	3.9 (0.97)	0.09 (0.022)	2.3 (0.57)	0.06 (0.015)
Ambient Conditions				
Dry Bulb Temperature, °F (°C)	56.5 (13.6)	8.92 (4.96)	54.8 (12.7)	8.44 (4.69)
Wet Bulb Temperature, °F (°C)	46.7 (8.15)	7.41 (4.12)	47.1 (8.41)	8.33 (4.63)
Barometric Pressure, in. Hg (kPa)	29.2 (98.6)	0.17 (0.58)		

6V-53T
TEST 39
FUEL ANALYSIS

Fuel: AL-12780-F (JP-8)

Property	ASTM Method	
Density, kg/L	D 1298	0.7793
API Gravity	D 1298	50.0
Distillation, °F	D 86	
IBP	D 86	308
10%	D 86	321
20%	D 86	322
30%	D 86	324
40%	D 86	326
50%	D 86	328
60%	D 86	330
70%	D 86	332
80%	D 86	336
90%	D 86	341
End Point	D 86	394
Residue, vol%	D 86	0.3
Distillation, °C	D 2887	
IBP	D 2887	140.1
10%	D 2887	153.1
20%	D 2887	160.2
30%	D 2887	165.9
40%	D 2887	170.1
50%	D 2887	173.0
60%	D 2887	176.7
70%	D 2887	179.0
80%	D 2887	181.3
90%	D 2887	186.0
End Point	D 2887	215.2
Flash Point, °F	D 56	103
Freeze Point, °C	D 2386	-59
Cetane Number	D 613	40.3
Kinematic Viscosity at 40°C, cSt	D 445	0.89
Cu Corrosion, at 100°C	D 130	1A
Total Acid Number	D 3242	0
Saturates, vol%	D 1319	80.7
Olefins, vol%	D 1319	1.4
Aromatics, vol%	D 1319	17.9
Sulfur, wt%	D 2622	<0.01
Mercaptan Sulfur, wt%	D 3227	<0.001
Saybolt Color	D 156	+26
Net Heat of Combustion, Btu/lb	D 1405	18548
Carbon, wt%	D 3178	85.49 ± 0.02
Hydrogen, wt%	D 3178	14.01 ± 0.01
Particulate Contamination, mg/L	D 2276	0.8
Existent Gum, mg/100 mL	D 381	0.4
Water Reaction	D 1094	1B
Water Separation Index, Modified	D 2550	76
Water Separation Characteristics, by Microseparometer	D 3948	88
Fuel System Icing Inhibitor, %	Fed. Std. 791	0.10
Electrical Conductivity, pS/m	D 3114	17

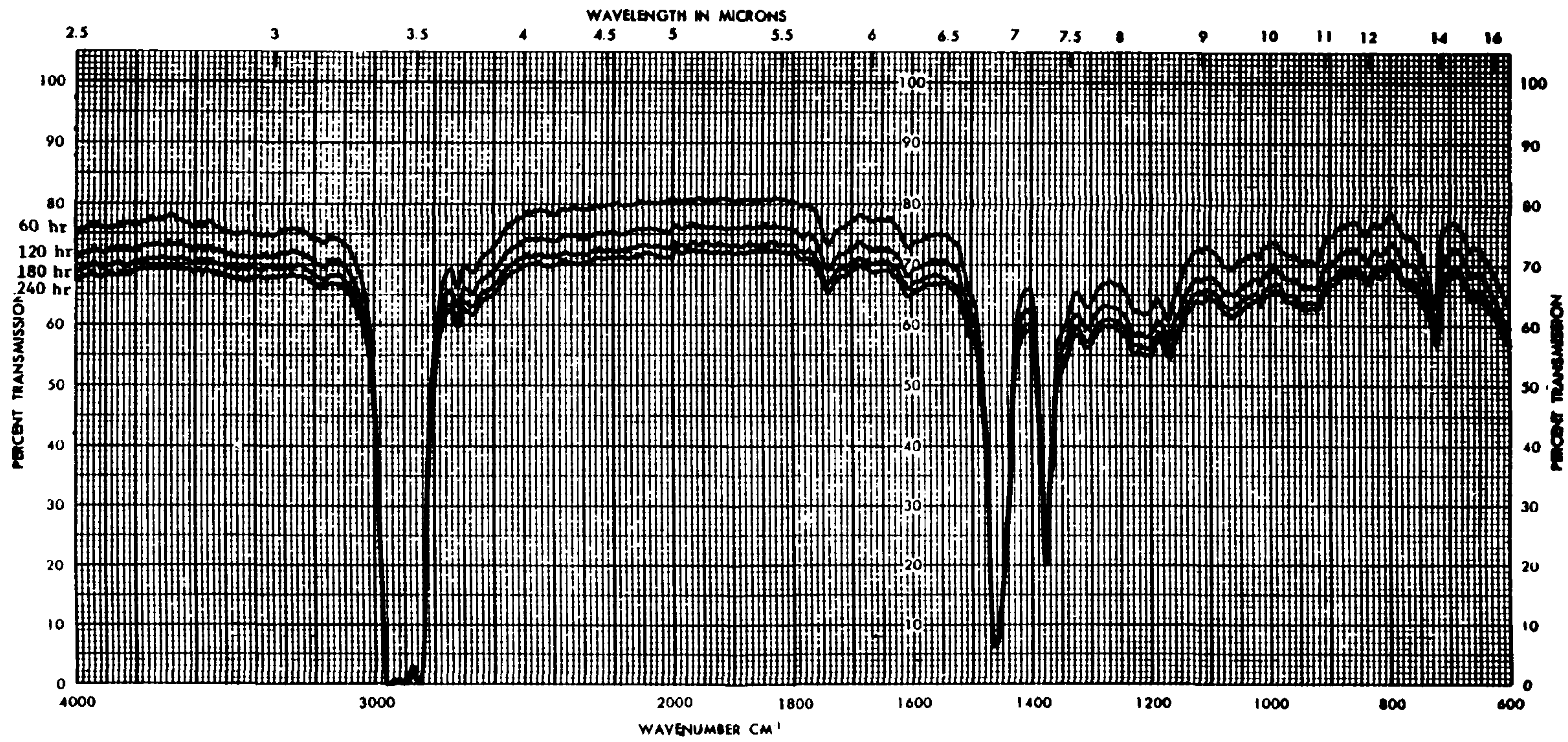
6V-53T
TEST 39
LUBRICANT ANALYSIS

Lubricant: AL-12634-L

	ASTM Test Method	Test Time, Hours												
		0	20	40	60	80	100	120	140	160	180	200	220	240
Kinematic Viscosity at 40°C (104°F) cSt	D 445	102.90	--	--	88.70	--	--	92.44	--	--	91.05	--	--	93.67
Kinematic viscosity at 100°C (212°F) cSt	D 445	11.66	10.48	10.72	10.89	10.99	11.05	11.13	10.88	10.91	11.01	11.01	11.17	11.22
Total Acid Number mg KOH/g	D 664	2.71	--	--	2.95	--	--	3.27	--	--	2.97	--	--	3.26
Total Base Number mg KOH/g	D 664	5.32	--	--	3.91	--	--	3.73	--	--	4.22	--	--	3.14
Pentane B Insolubles wt%	D 893	0.02	--	--	0.14	--	--	0.23	--	--	0.14	--	--	0.20
Toluene B Insolubles wt%	D 893	0.01	--	--	0.12	--	--	0.18	--	--	0.12	--	--	0.17
Flash Point, °C	D 92	238	--	--	--	--	--	227	--	--	--	--	--	224

6V-53T
TEST 39
INFRARED SPECTRUM

Lubricant: AL-12634-L



6V-53T
TEST 39
TOTAL CONSUMPTION AND WEAR METALS BY XRF

Lubricant: AL-12634-L

Test Time, Hours	Total Oil Consumed, lb (kg)		Wear Metals, ppm Fe	Cu
0	0		59	11
20	6.44	(2.92)	83	<10
40	15.03	(6.82)	97	<10
60	23.32	(10.58)	83	<10
80	33.44	(15.17)	103	<10
100	42.06	(19.08)	134	<10
120	Oil change		119	<10
140	49.16	(22.30)	45	<10
160	58.55	(26.56)	51	<10
180	68.35	(31.00)	49	<10
200	78.29	(35.51)	52	<10
220	87.99	(39.91)	46	<10
240	101.70	(46.13)	49	<10

Average oil consumption rate: 0.42 lb/hr (0.19 kg/hr)

6V-53T
TEST 39
*WEAR MEASUREMENTS**

Lubricant: AL-12634-L

Cylinder Liner Bore Diameter Change**

Cylinder Number

	1R T-AT***	1R F-B	2R T-AT	2R F-B	3R T-AT	3R F-B
Top	0.0016 (0.041)	0.0009 (0.023)	0.0008 (0.020)	0.0050 (0.13)	0.0010 (0.025)	-0.0004 (-0.010)
Middle	0.0008 (0.020)	0.0021 (0.053)	0.0003 (0.008)	0.0022 (0.056)	0.0002 (0.005)	0.0002 (0.005)
Bottom	-0.0001 (-0.002)	0.000	-0.0001 (-0.002)	-0.0001 (-0.002)	0.0010 (0.025)	-0.0001 (-0.002)

Average Change

	T-AT	F-B
Top	0.0011 (0.028)	0.0055 (0.14)
Middle	0.0004 (0.010)	0.0015 (0.038)
Bottom	0.0003 (0.008)	-0.0001 (-0.002)

Overall average change: 0.0014 (0.036)

Piston Ring End Gap Change

Ring Number	1L	2L	3L	1R	2R	3R	Average Change
1	0.002 (0.05)	0.002 (0.05)	0.000	0.003 (0.08)	0.004 (0.10)	0.000	0.002 (0.05)
2	0.001 (0.02)	0.001 (0.02)	0.000	0.000	0.002 (0.05)	0.000	0.001 (0.02)
3	0.001 (0.02)	0.001 (0.02)	0.000	0.000	0.001 (0.02)	0.000	0.001 (0.02)
4	0.000	0.000	0.000	0.001 (0.02)	0.002 (0.05)	0.001 (0.02)	0.001 (0.02)
5	0.005 (0.13)	0.060 (1.52)	0.004 (0.10)	0.012 (0.30)	0.009 (0.23)	0.004 (0.10)	0.016 (0.41)
6	0.004 (0.10)	0.047 (1.19)	0.002 (0.05)	0.011 (0.28)	0.004 (0.10)	0.003 (0.08)	0.012 (0.30)
7	0.003 (0.08)	0.039 (0.99)	0.003 (0.08)	0.008 (0.20)	0.003 (0.08)	0.004 (0.10)	0.010 (0.02)

Overall average change: 0.006 (0.15)

Average Piston Ring Radial Width Change

Ring Number	1L	2L	3L	1R	2R	3R	Average Change
1	0.0006 (0.015)	0.0001 (0.002)	-0.0002 (-0.005)	-0.0003 (-0.008)	-0.0013 (-0.033)	0.0001 (0.002)	-0.0002 (-0.005)
2	0.0001 (0.002)	0.0000	0.0007 (0.018)	0.0000	-0.0002 (-0.005)	-0.0052 (0.132)	-0.0008 (-0.020)
3	0.0004 (0.010)	0.0004 (0.010)	0.0001 (0.002)	-0.0003 (-0.008)	-0.0013 (-0.033)	-0.0012 (-0.030)	-0.0003 (-0.008)
4	0.0002 (0.005)	0.0003 (0.008)	0.0001 (0.002)	-0.0004 (-0.010)	-0.0003 (-0.008)	-0.0003 (-0.008)	-0.0001 (-0.002)

Overall average change: -0.0004 (-0.010)

Bearing Weight Loss

Main Bearings	#1	#2	#3	#4	Average Change
Upper	0.000395 (11.2)+	0.000458 (13.0)	0.000522 (14.8)	0.000832 (23.6)	0.000552 (15.6)
Lower	0.00102 (28.8)	0.00365 (103.5)	0.00201 (57.1)	0.00222 (62.8)	0.00222 (63.0)

Overall Average Change: 0.00139 (39.3)

Rod Bearings	1L	2L	3L	1R	2R	3R	Average Change
Upper	0.000621 (17.6)	0.000790 (22.4)	0.00135 (38.4)	0.000360 (10.2)	0.000783 (22.2)	0.000896 (25.4)	0.000801 (22.7)
Lower	0.00017 (4.8)	0.00015 (4.3)	0.00013 (3.7)	0.00011 (3.1)	0.000078 (2.2)	0.00016 (4.4)	0.00013 (3.8)

* All dimensions are given in inches (mm).
** After-test measurements not taken for cylinders 1L, 2L and 3L.
*** T-AT = Thrust-Antithrust Direction; F-B = Front-Back Direction.
\+ Measurements are in ounces (mg).

6V-53T
TEST 39
POST TEST ENGINE CONDITION AND DEPOSITS

Lubricant: AL-12634-L

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
A. Cylinder Liner							
Intake Port Plugging, % restriction	<1	<1	<1	<1	<1	<1	<1
Liner Scuffing, % Area							
Thrust	0	28.00	2.00	94.00	46.00	0	28.33
Anti-Thrust	6.00	71.00	12.00	61.00	64.00	10.00	37.33
% Total Area Scuffing	3.00	44.50	7.00	77.50	55.00	5.00	32.83
						Overall:	32.83
% Area Bore Polished							
Thrust	2.00	2.00	5.00	0	2.00	10.00	3.50
Anti-Thrust	5.00	3.00	5.00	2.00	3.00	2.00	3.33
% Avg. Area Bore Polished	3.50	2.50	5.00	1.00	2.50	6.00	3.42
						Overall:	3.42
B. Pistons							
Ring Face Distress, (demerits)							
No. 1	7.50	9.50	19.00	25.25	13.75	16.50	15.08
No. 2	6.75	21.25	11.25	10.00	10.50	4.00	10.63
No. 3	13.75	36.25	18.75	22.50	23.75	16.25	21.88
No. 4	16.50	26.50	11.25	25.00	26.25	17.50	20.50
						Overall:	17.02
Piston Skirt Rating*							
Thrust	10%SC	35%SC	S	10%SC	S	5%SC	
Anti-Thrust	5%SC	5%SC	S	15%SC	10%SC	10%SC	
Upper Oil Control Ring Expander Force (lbs)	19.4	20.4	20.2	20.4	20.2	20.2	20.1
Piston WTD Rating**	195.000	230.750	274.375	230.625	249.250	289.125	244.854
Ring Sticking***							
No. 1	F	F	F	P	F	F	
No. 2	F	F	F	F	F	F	
No. 3	F	F	F	F	F	F	
No. 4	F	F	F	F	F	F	
C. Exhaust Valves							
Deposits+							
Head	BHC+	BHC	BHC	AHC	AHC	AHC	
Face	1/4AHC (all)						
Tulip	AHC (all)						
Stem	9 Lacquer++ (all)						
Surface Condition+++							
Freeness in Guide	F	F	F	F	F	F	
Head	Normal (all)						
Face	Normal (all)						
Seat	LL+++	LL	N	LL	LL	LL	
Stem	Normal (all)						
Tip	Normal (all)						
D. Other Ratings							
Bearing Surface Condition							
Main Bearings	No abnormalities						
Rod Bearings	3L connecting rod bearing has copper showing (it was this way after break-in)						
Injector Needles							
Tip Demerits	7.60	7.20	9.00	9.00	8.60	9.00	8.40
Shaft Demerits	1.50	0.90	0.90	0.95	0.00	1.10	0.89

* L = Light, S = Scratches, PM = Plating Melted, N = Normal, SC = Scuffing, B = Burn
** CRC Weighted Total Deposits (0 = least, 900 = most)
*** HS = Hot Stuck, CS = Cold Stuck, P = Pinched, F = Free, N = Normal, CH = Chipped, C = Collapsed
\+ HC = Hard Carbon; the number-letter, prefix indicates carbon depth with 1/4A = least to J = most
\+\+ The higher the number, the darker the Lacquer (0 = lightest, 9 = darkest)
\+\+\+ F = Free, N = Normal, LL = Light Leakage

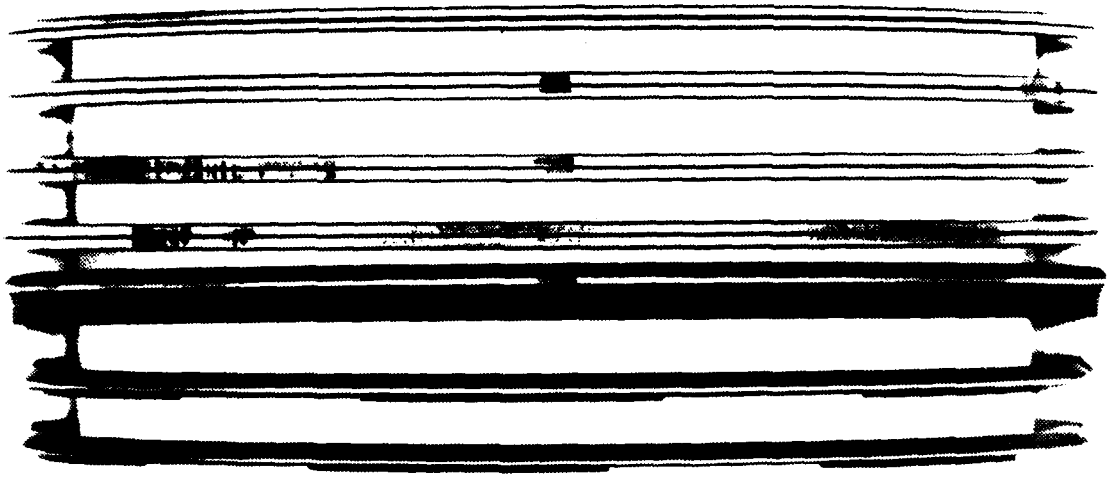
6V-53T
TEST 39
FUEL INJECTOR TESTS

Fuel: AL-12780-F (JP-8)

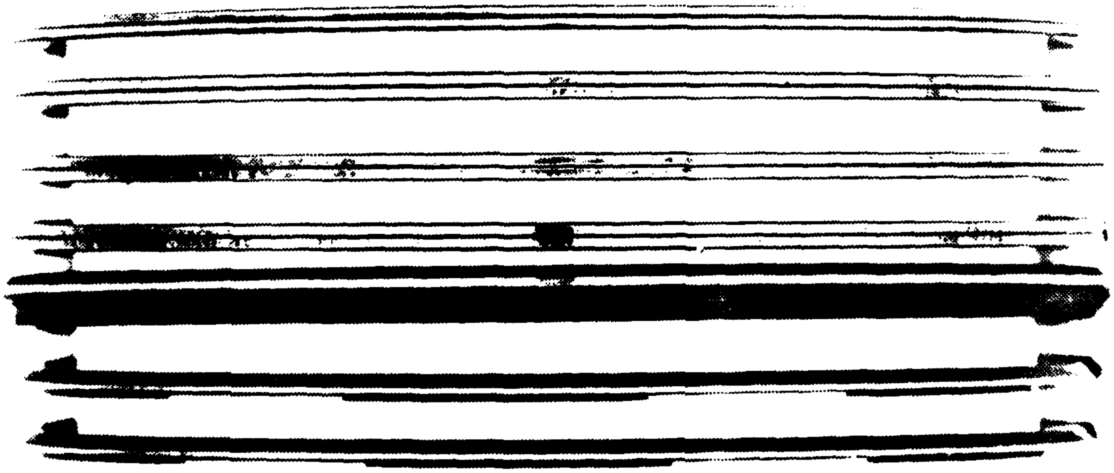
	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
Pop-Off Pressure, Psi							
Before Test	144	138	136	132	122	126	
After Test, Before Cleaning	120	128	None	126	135	125	
After Test, After Cleaning	None	130	132	127	131	130	
Spray Pattern							
Before Test	----------Good----------						
After Test, Before Cleaning	G*	G	P	G	G	G	
After Test, After Cleaning	----------Good----------						
Atomization							
Before Test	----------Good----------						
After Test, Before Cleaning	F	G	P	G	G	G	
After Test, After Cleaning	P	G	G	G	G	G	
Injector Tip Flow Readings, Relative Flow With 5 Psi Air							
Before Test	15.8	15.8	16.0	17.0	15.8	16.0	
After Test, Before Cleaning	15.7	15.05	15.05	15.5	15.5	16.0+	
After Test, After Cleaning	16.0+	15.6	16.0+	16.0+	15.0	15.35	
Ml Fuel Per 1000 Engine Strokes							
Before Test	98	93	95	98	98	98	97
After Test, Before Cleaning	97	92	98	97	97	98	96.5
After Test, After Cleaning	97	93	98	98	98	98	97

* G = Good, F = Fair, P = Poor
\+ Off the Flowmeter Scale

6V53T(#39)
1-L



6V53T(#39)
1-R



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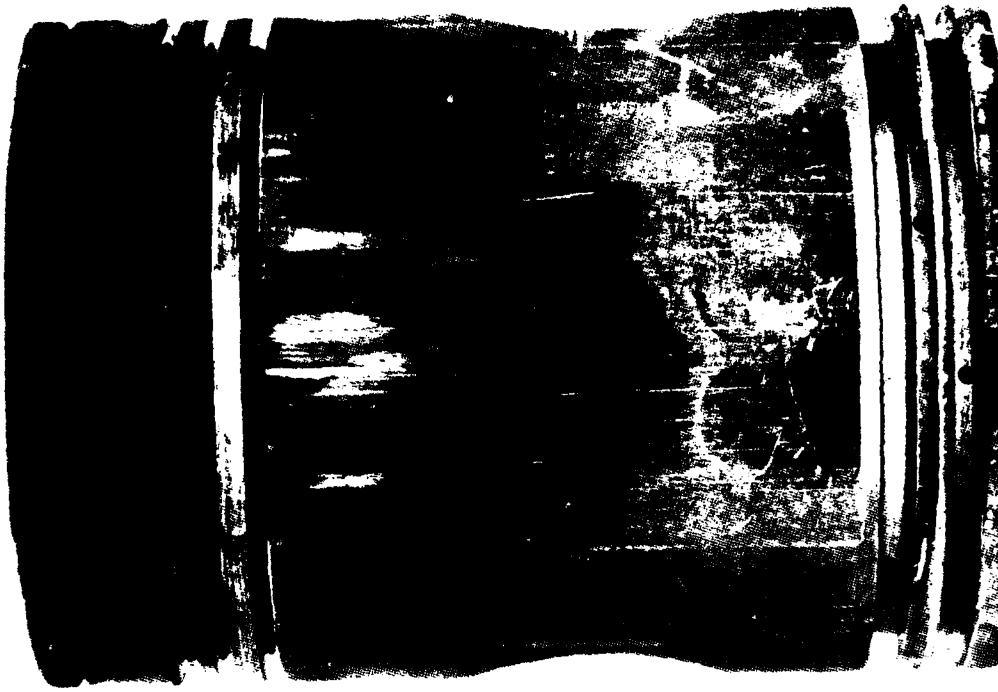
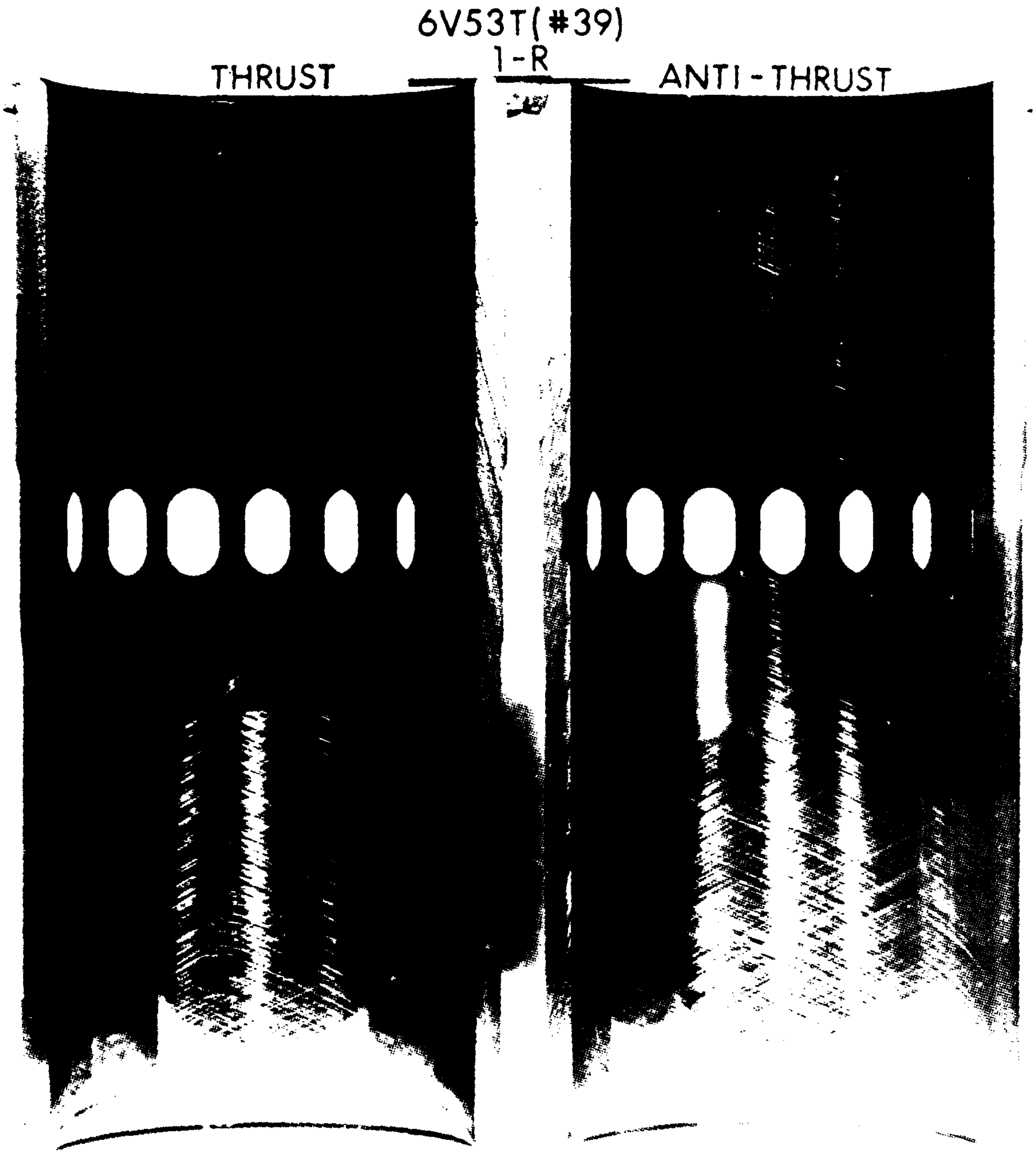
1-R-AT



6V53T(#39)
1-R-T

6V53T(#39)
1-L-T

6V53T(#39)
1-L-AT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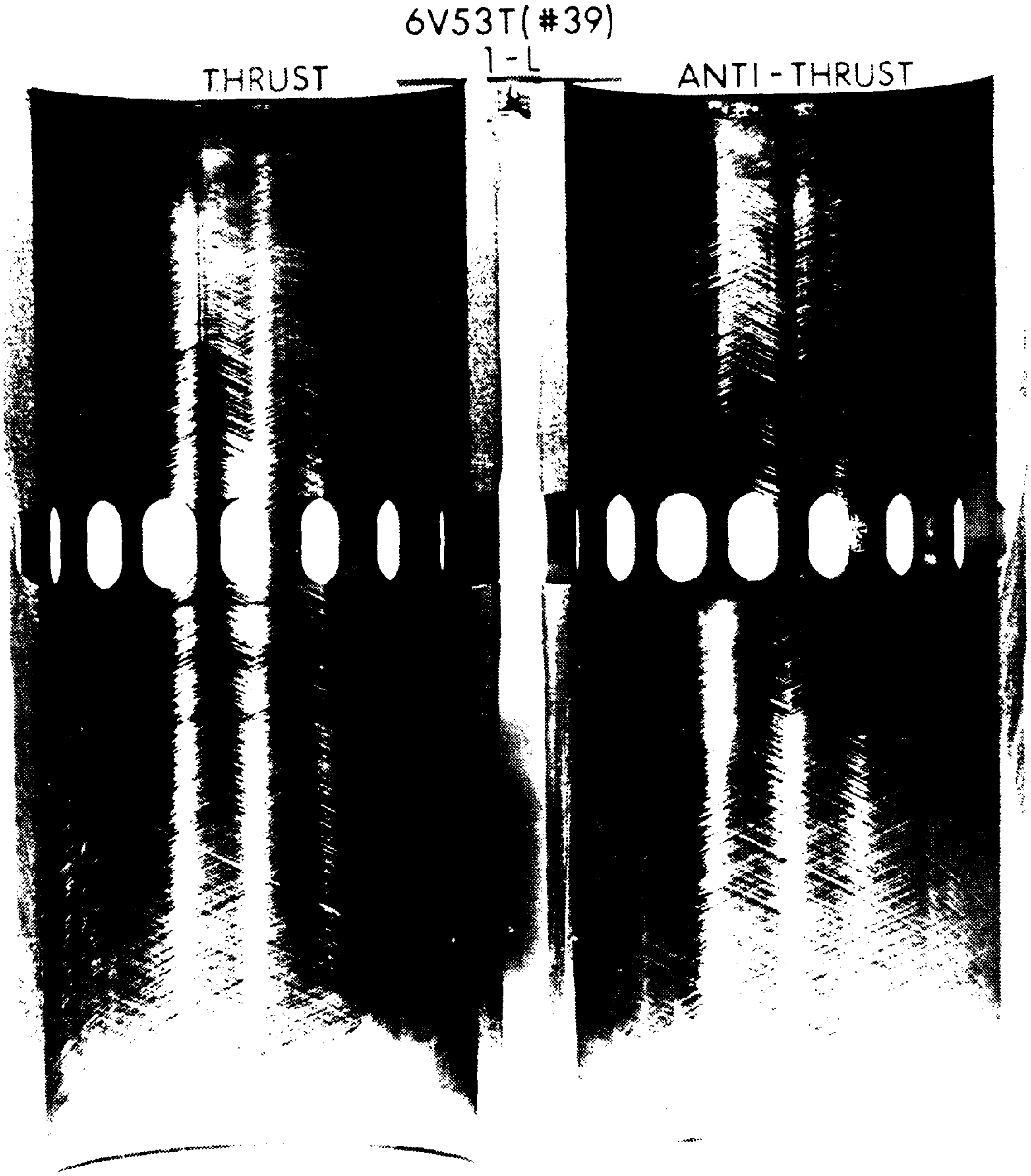
THRUST
1-R
ANTI-THRUST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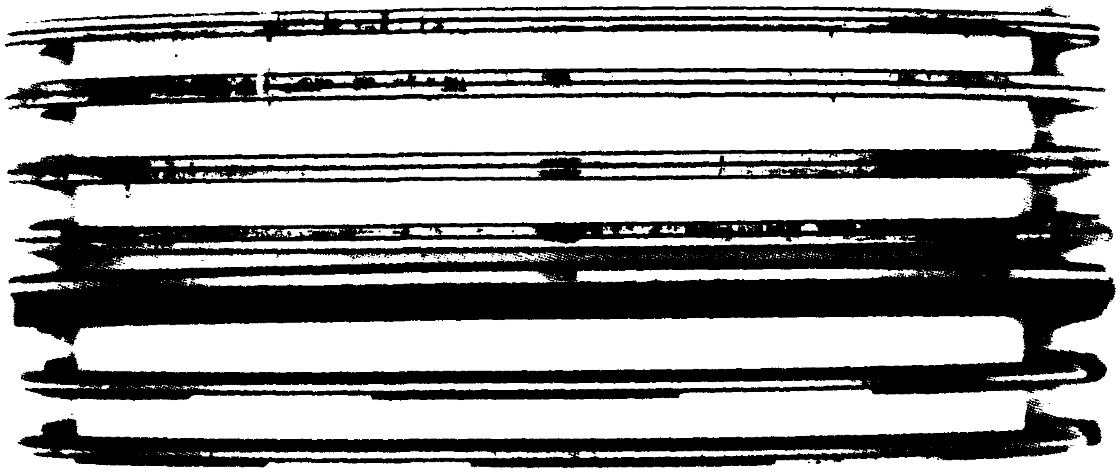
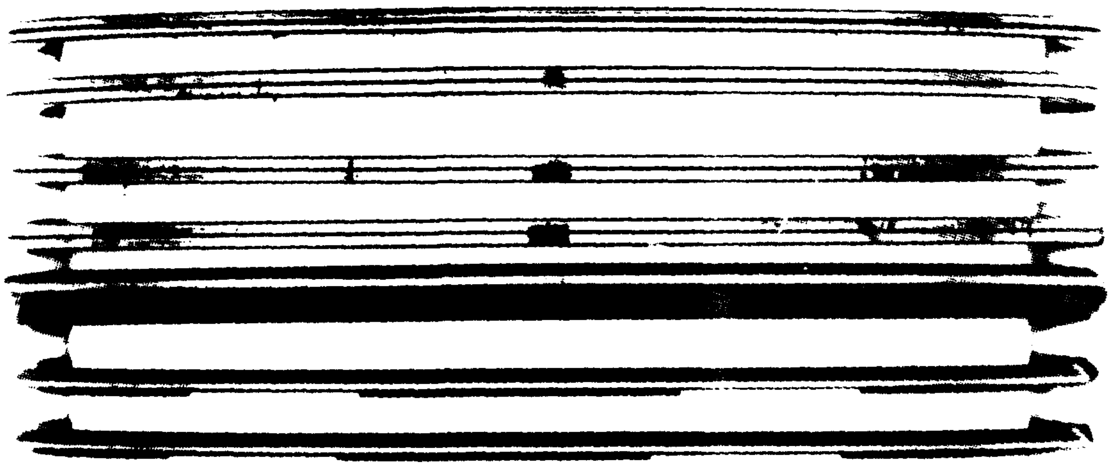
1-L
THRUST
ANTI-THRUST

6V53T(#39)
2-L



6V53T(#39)
2-R

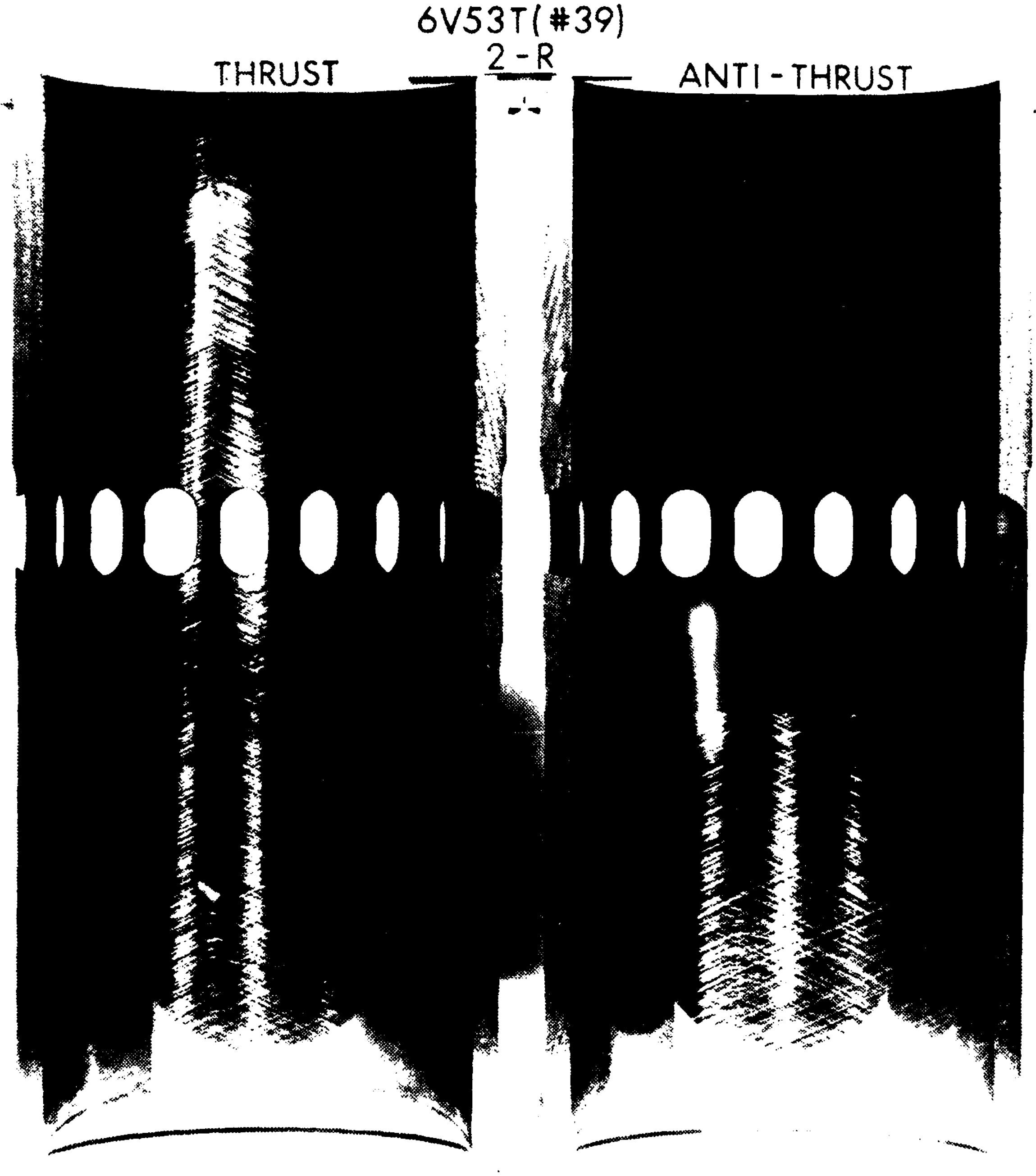


6V53T(#39)
2-R-T

6V53T(#39)
2-R-AT

6V53T(#39)
2-L-T

6V53T(#39)
2-L-AT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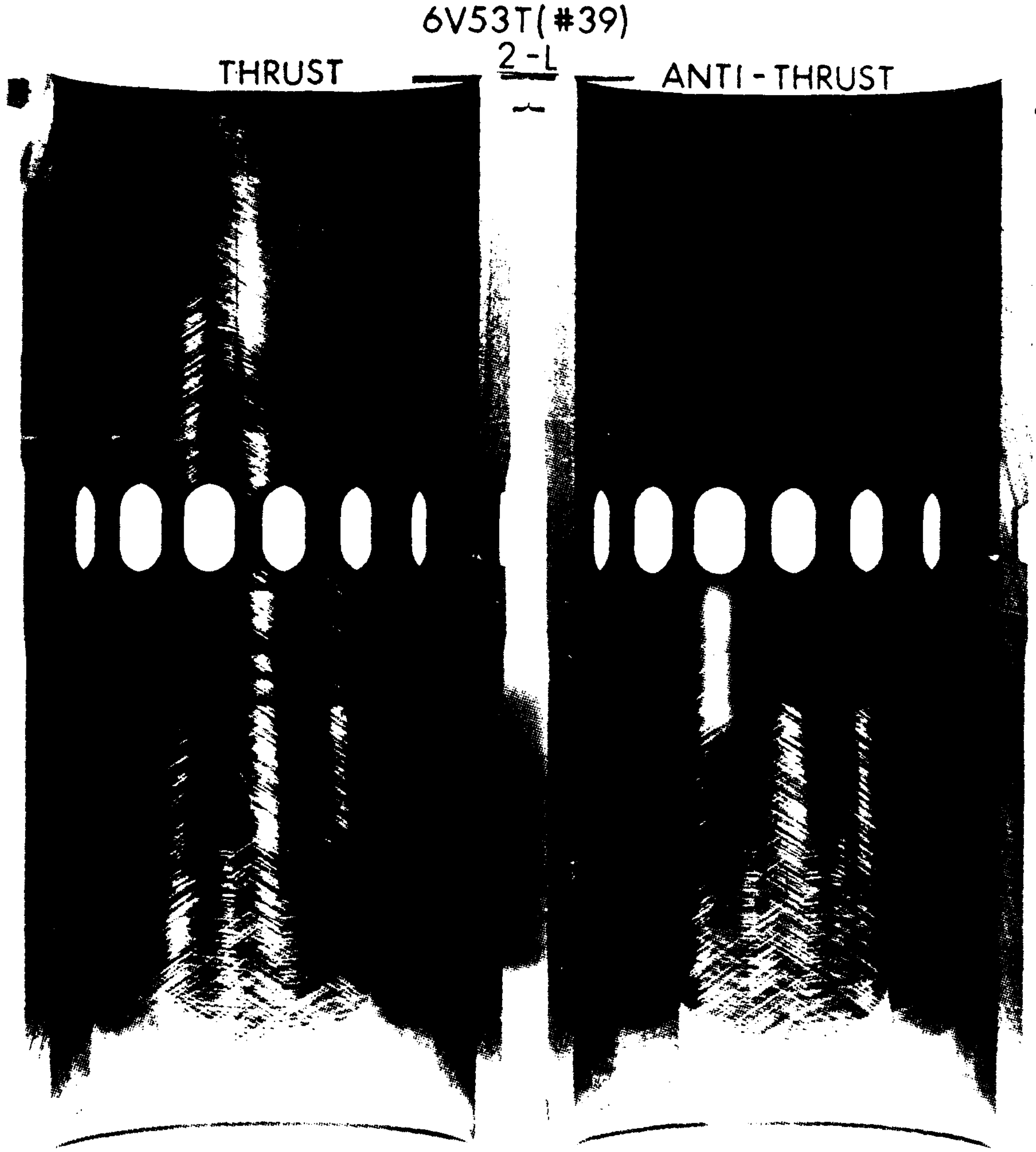
2-R
THRUST
ANTI-THRUST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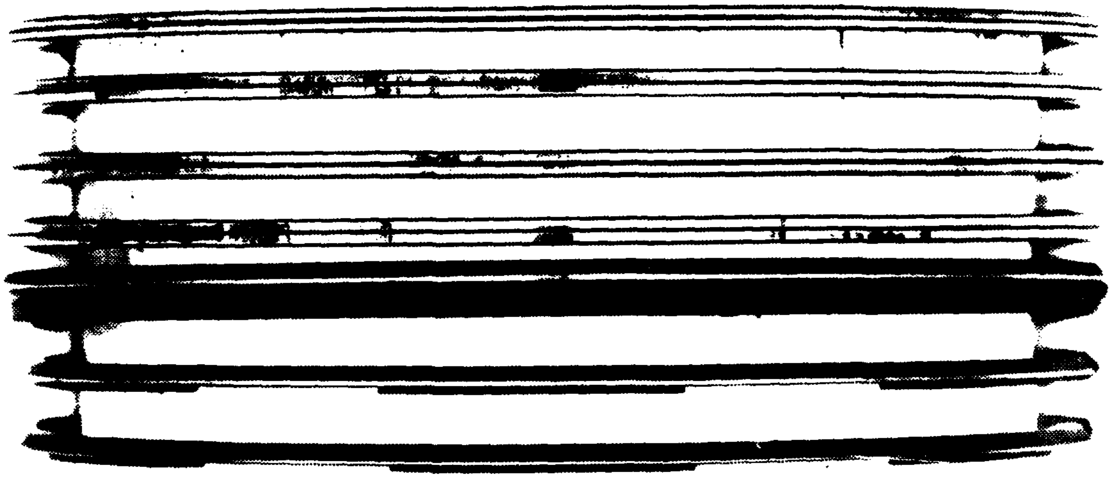
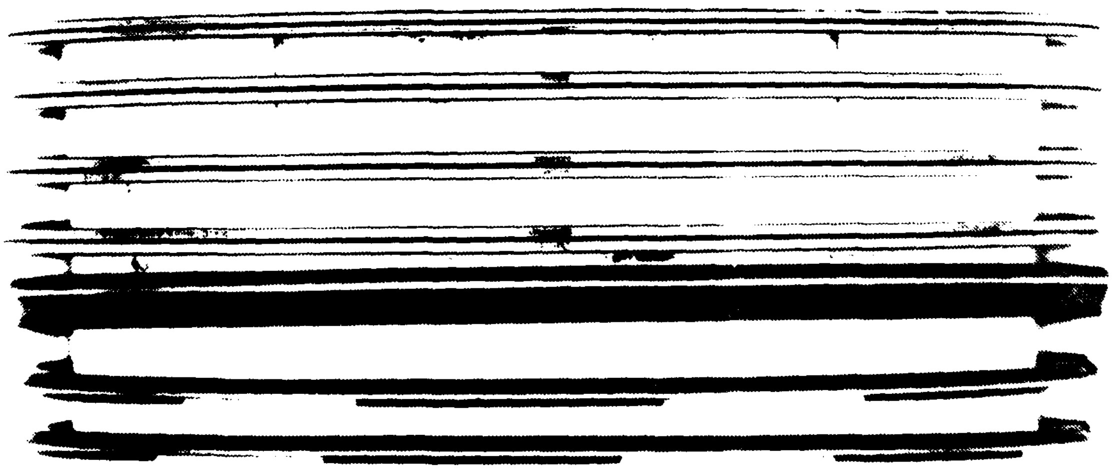
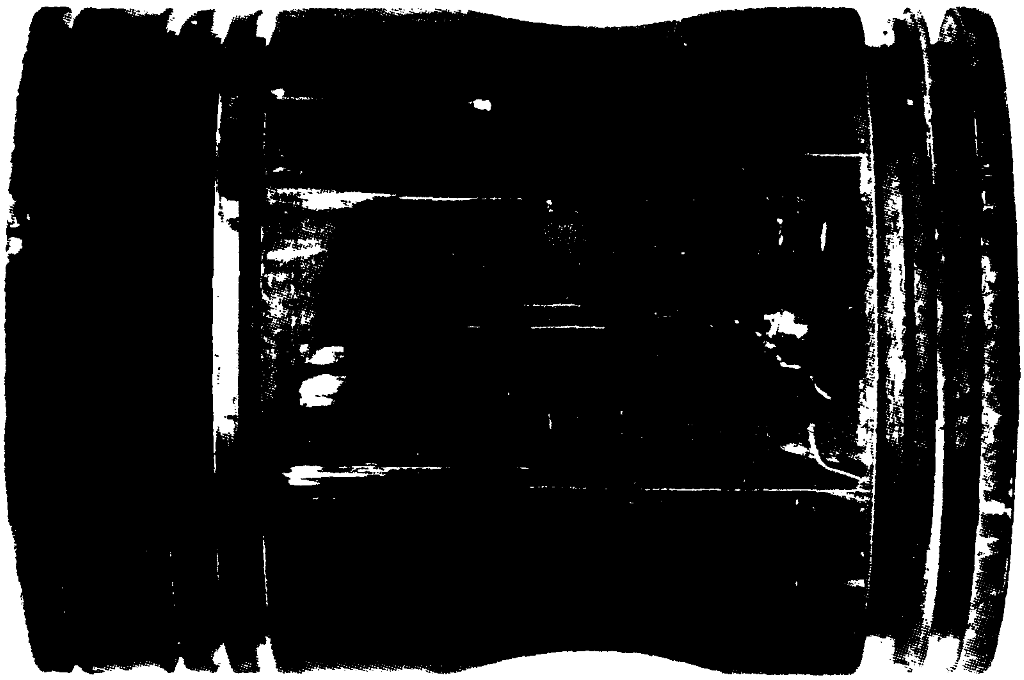
THRUST
2-L
ANTI-THRUST

6V53T(#39)
3-L



6V53T(#39)
3-R





6V53T(#39)
3-R-AT

6V53T(#39)
3-R-T

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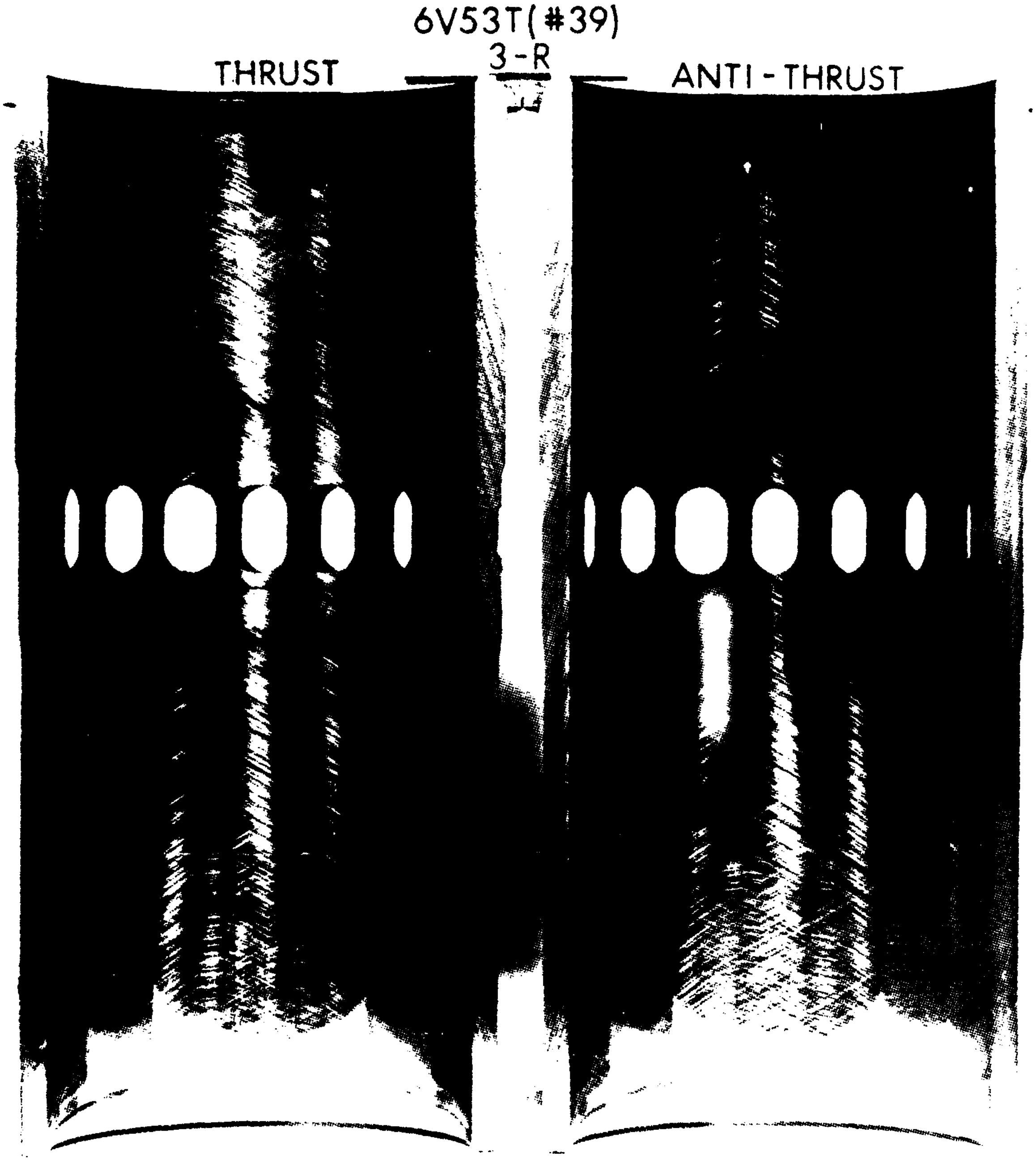
3-L-AT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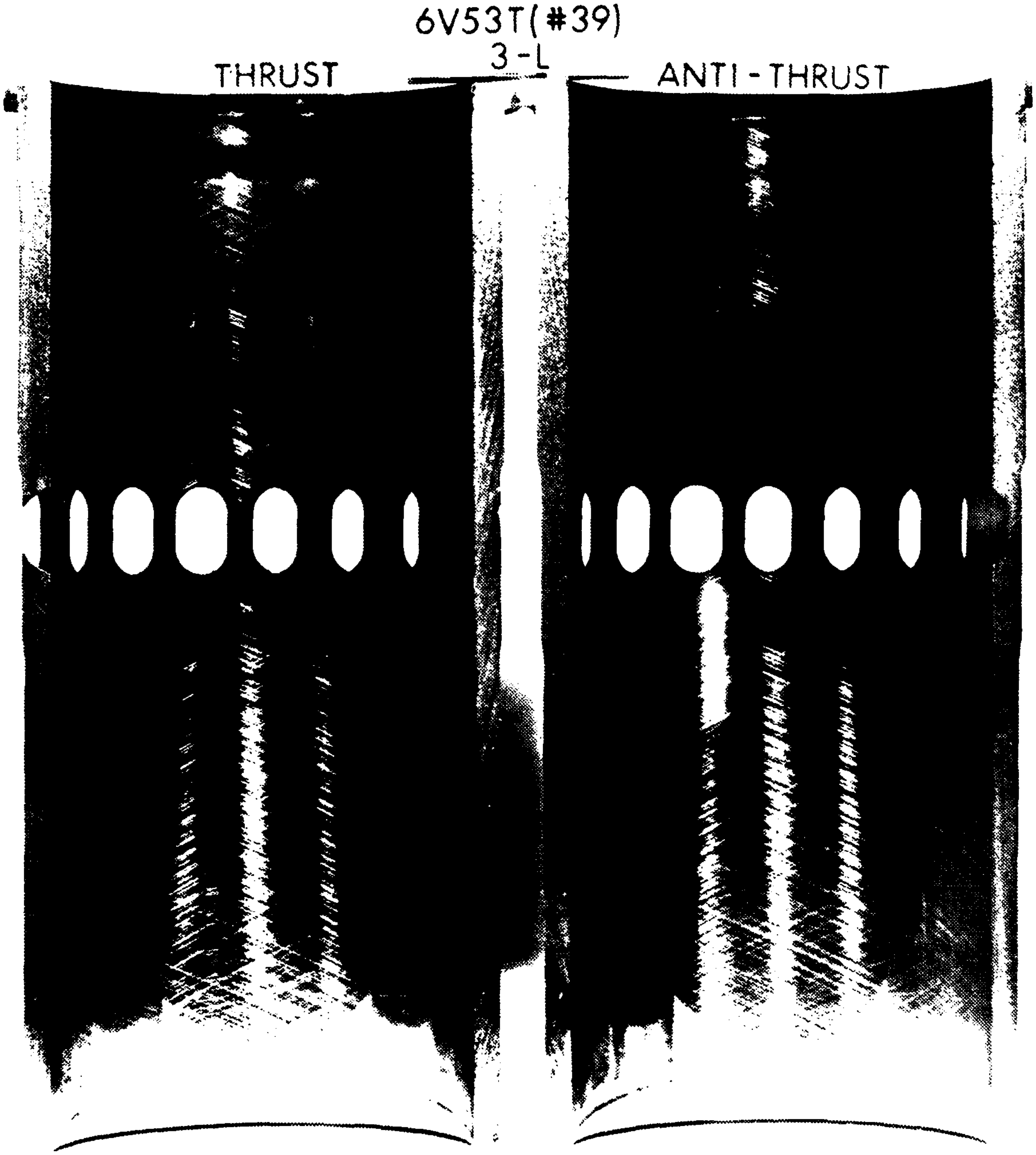
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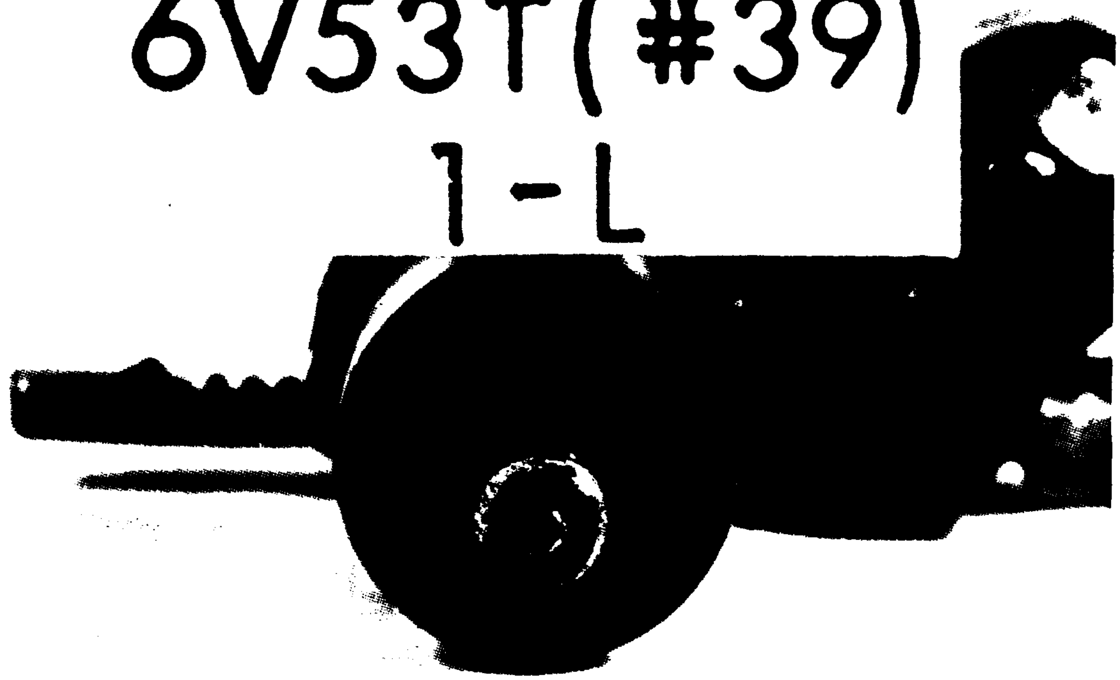
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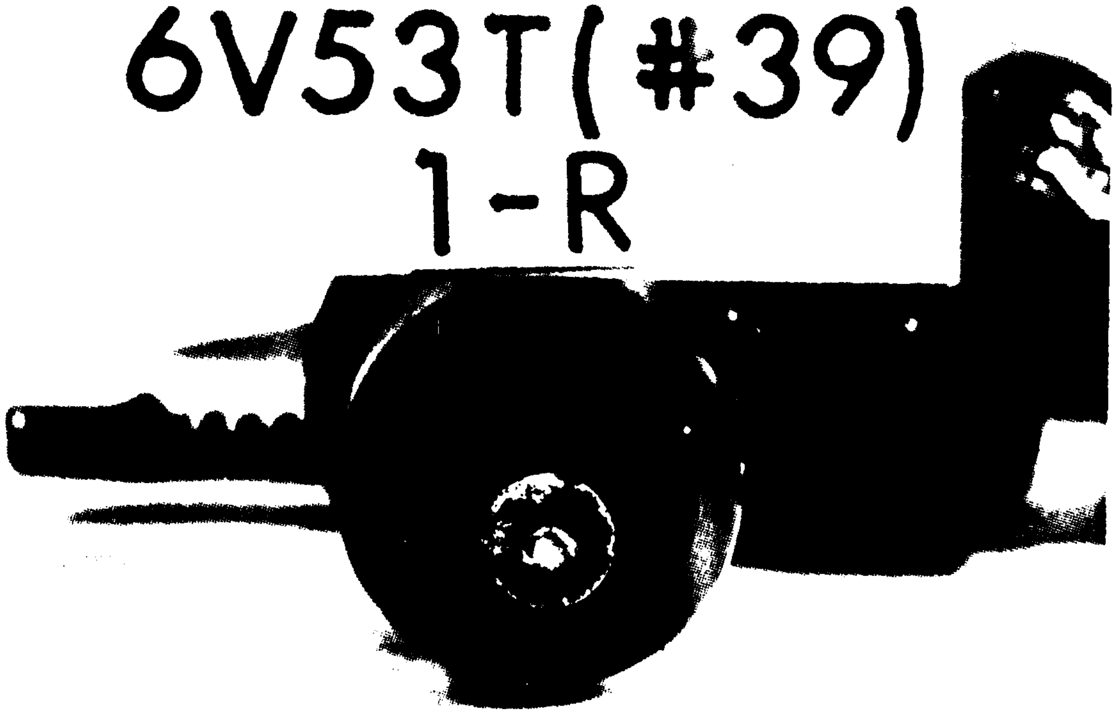
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L3
L2
L1
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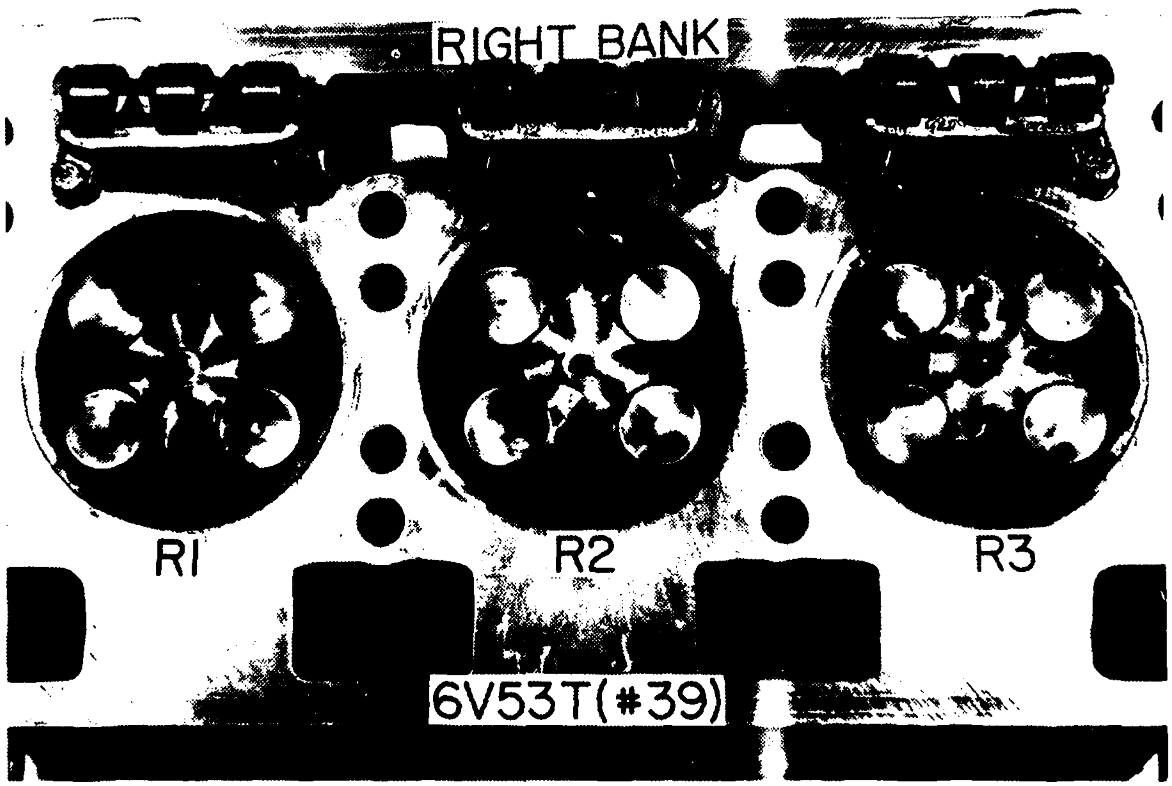
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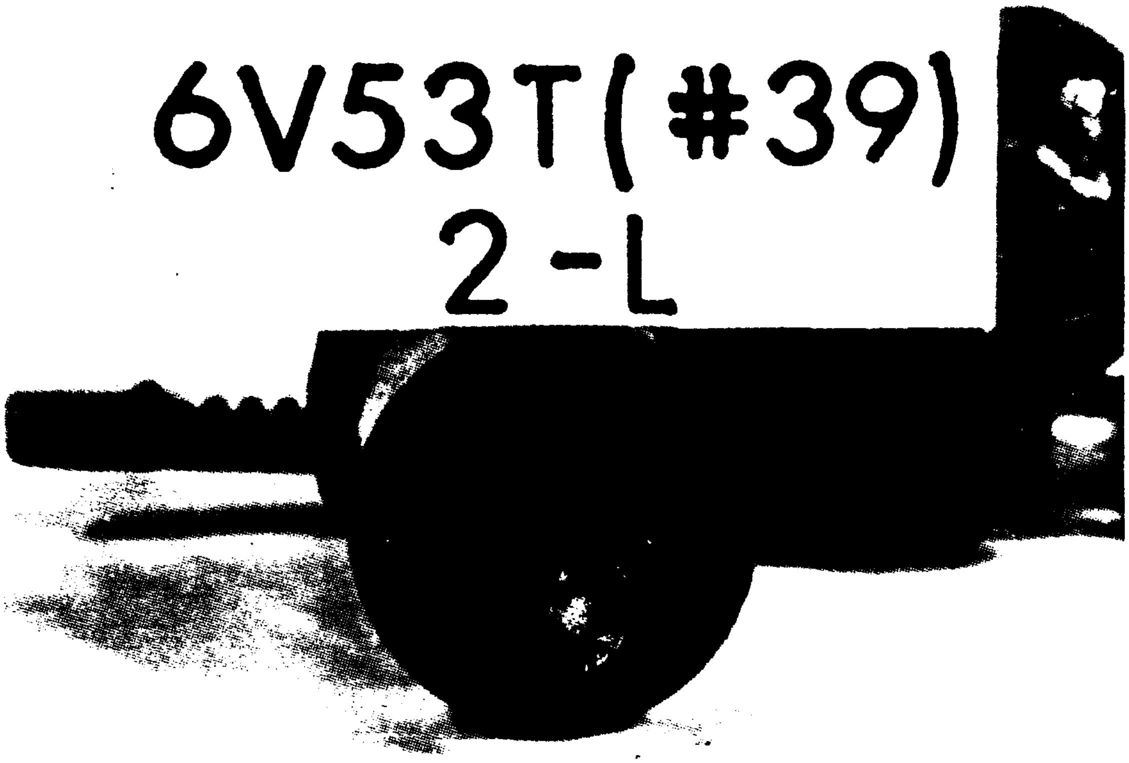
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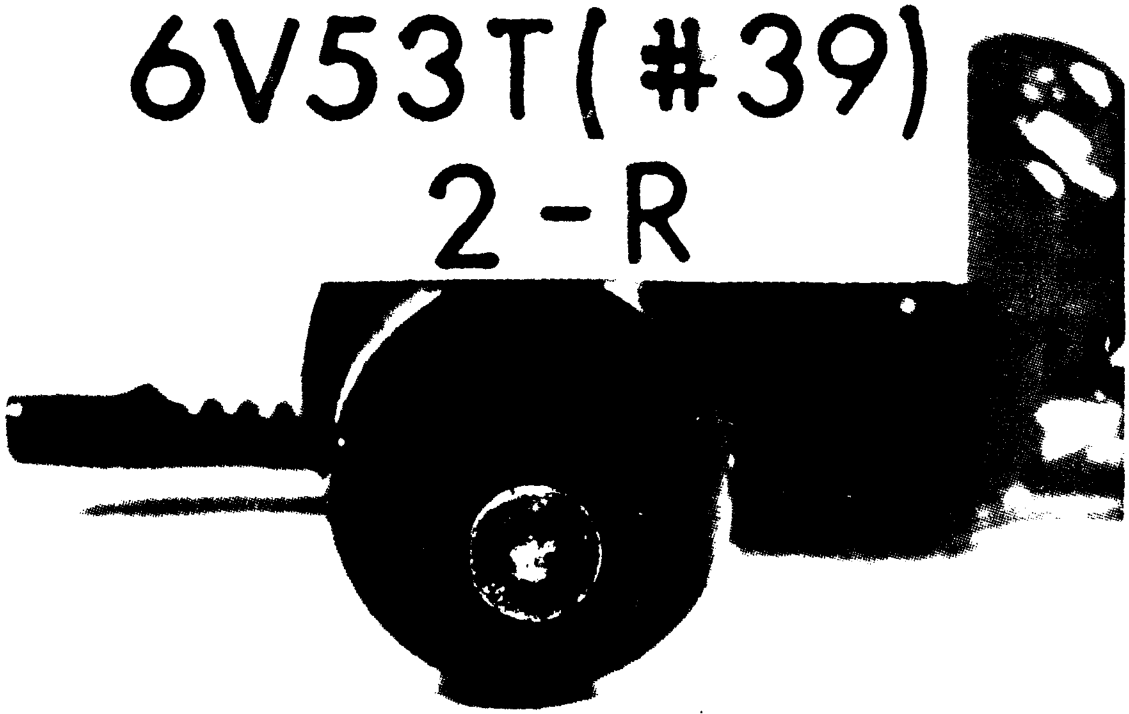
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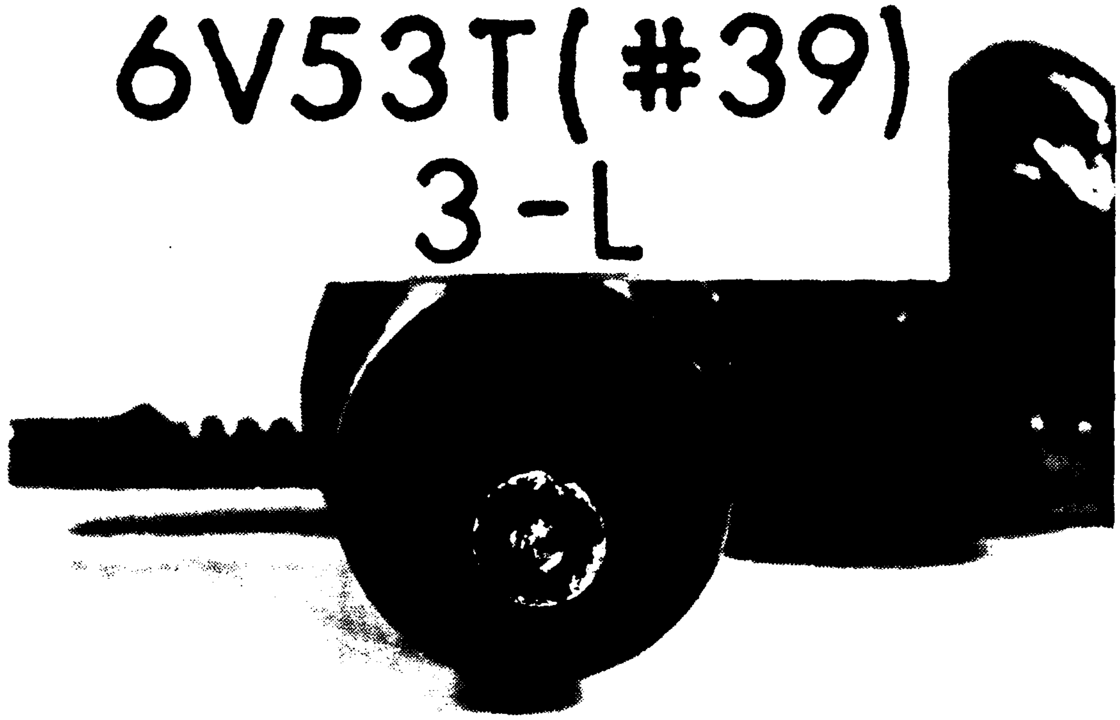
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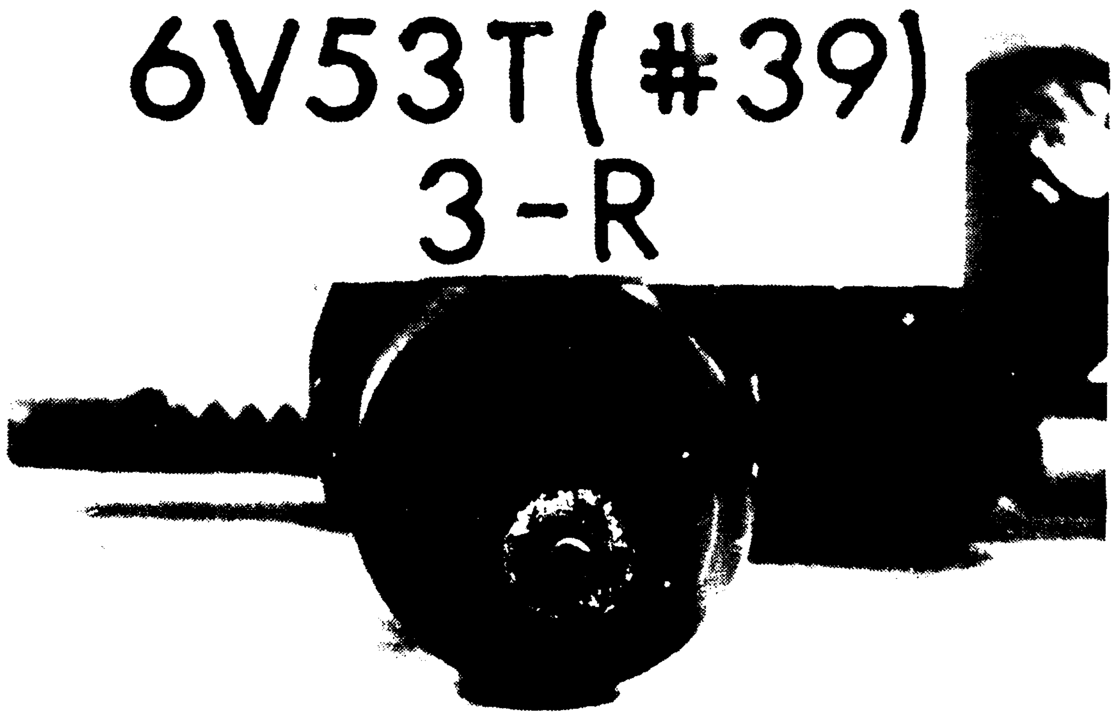
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